SAN FRANCISCO PUBLIC UTILITIES COMMISSION

Independent Advisory Panel for Single-Family Water Reuse Applications Report

December 2024
FINAL REPORT

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Definitions

Best Management Practice	Commonly employed practices for managing and mitigating risk.
Enteric Pathogens	Viruses, bacteria, and protozoa that are associated with gastrointestinal illnesses transmitted via the fecal-oral route.
Graywater	Domestic wastewater collected from sources other than toilets, kitchen sinks, and dishwashers (*e.g.*, bathroom sinks, showers, clothes washers). May be source-separated or combined across sources (*i.e.*, mixed graywater).
Log_{10} Reduction Target	Pathogen control requirement in terms of the log_{10} (*i.e.*, tenfold) inactivation or removal of pathogens (*e.g.*, 4 log corresponds to 99.99 percent inactivation/removal).
Onsite Treatment	Water treatment system on the same premises, district or neighborhood scale for the treated water end use.
Opportunistic Pathogens	Environmental microorganisms that can cause infections under certain exposure and host conditions. Typically encompasses *Legionella* spp., *Mycobacterium* spp., and *Pseudomonas aeruginosa* but can also refer to other microorganisms, including fungi.
Recirculating Shower	Water is recirculated within a single shower use and discharged to the drain following the conclusion of the shower.
Recirculating Clothes Washer	Clothes washers that collect, store, and treat rinse water for recirculation as source water for the clothes washer during subsequent loads.
Single-Family Dwelling	Dwelling in which a small unit of persons reside together in a single-family home, apartment, or condominium. An estimate of 5 persons is used to align with past risk assessments. Does not include dwellings used as vacation rentals.
Single-Family Graywater System	Graywater collection, treatment, distribution, and usage within a single-family dwelling.
Quantitative Microbial Risk Assessment	Systematic assessment of the likelihood of negative health consequences, such as infections or illnesses, when a population or an individual is exposed to pathogens, which can be used to determine the corresponding treatment level needed to reduce risk to an acceptable level. Follows the process of hazard identification, exposure assessment, dose-response assessment, and risk characterization.

Abbreviations

ACH	air-conditioning condensate harvesting
ANSI	American National Standards Institute
BOD	biochemical oxygen demand
BOD5	5 day biochemical oxygen demand
BMP	Best Management Practices
DNW	Decentralized non-potable water
EPA	United States Environmental Protection Agency
EPA-ORD	United States Environmental Protection Agency, Office of Research and Development
gpcd	gallons per capita per day
gpd	gallons per day
GWMBR	graywater membrane bioreactor
HPC	heterotrophic plate count
IAP	Independent Advisory Panel
IAPMO	The International Association of Plumbing and Mechanical Officials
J/m^2	joules per square meter
L/min	liters per minute
LRT	log_{10} reduction target
LRV	log_{10} reduction value
MBR	membrane bioreactor
MCL	maximum contaminant level
mg/L	milligrams per liter
mJ/cm^2	millijoules per square centimeter
NPR	non-potable reuse
NSD	not sufficient data to access
NSF	NSF International (previously National Sanitation Foundation)
NTU	Nephelometric Turbidity Units
O&M	operations and maintenance
PAH	polycyclic aromatic hydrocarbons
PBDE	polybrominated diphenyl ethers
PCB	polychlorinated biphenyls
PFAS	per- and polyfluoalkyl substances
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonic acid
pppy	per person per year

QMRA	Quantitative microbial risk assessment
RME	responsible management entity
RWH	rainwater harvesting
SFPUC	San Francisco Public Utilities Commission
TSS	total suspended solids
U.S.	United States
UV	ultraviolet radiation
UVA	ultraviolet radiation absorbance
WE&RF	Water Environment and Reuse Foundation
WWMBR	wastewater membrane bioreactor

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EXECUTIVE SUMMARY

Water is a defining issue of our time. Cities across the world are rethinking the traditional approach to water systems in the face of drought, extreme weather, and associated impacts on water quantity and quality. In San Francisco, onsite water treatment systems are required in large multi-family and commercial buildings. These onsite treatment systems capture graywater or blackwater for non-potable uses such as toilet flushing and irrigation. The San Francisco Public Utilities Commission (SFPUC) is now looking to expand the possibility of treating water onsite for reuse at the single-family dwelling scale. Emergent technologies, such as single-family graywater systems and recirculating showers, are already available in the marketplace today. While single-family graywater systems have been installed in the United States (U.S.), recirculating showers implementation has been largely limited to Europe. Considerations of new technologies like recirculating clothes washers are underway. Together these technologies may present opportunities for water savings within the single-family dwelling.

Amidst these opportunities, the SFPUC's top priority is to prevent infections and illnesses associated with recycled and/or recirculated water exposure, while remaining cognizant of issues related to both operation and maintenance and life cycle costs and environmental impacts associated with single-family reuse technology. To assess reuse applications in single-family settings and to provide technical and policy recommendations on the feasibility of single-family reuse implementation, the SFPUC established an Independent Advisory Panel (IAP) consisting of field experts in risk assessment, public health and regulation, policy, sustainable water systems, and engineering. The objective of the IAP is to assess public health considerations, treatment needs, and best management practices for single-family water reuse applications.

The IAP was tasked with:

- Reviewing the latest literature pertaining to risk management for single-family and appliance-scale reuse.
- Describing public health considerations.
- Considering appropriate risk management approaches.
- Identifying treatment considerations.
- Evaluating operation and maintenance approaches.

- Considering the life cycle costs and environmental impacts associated with reuse fixtures and appliances.
- Providing recommendations for managing these systems to protect human health.

The IAP was not tasked with:

- Evaluating specific products currently on the marketplace.
- Validating or refuting manufacturer product claims.

The recommendations by the IAP are not specific to any commercially available products, but rather generally describe features deemed to be important to be protective of public health.

The IAP evaluated the risk of enteric pathogen transmission through reused water in single-family dwellings relative to the baseline risk of illness transmission in the dwelling from person-to-person contact, contaminated objects and surfaces, and existing waterborne pathways. The IAP's recommendations were formed using available information on pathogen occurrence and health risks associated with these single-family water reuse systems and therefore conservative assumptions were made where data limitations remain. The IAP provided generalized recommendations for these systems that are not based on specific products in the marketplace. Key takeaways from the IAP's work are summarized below.

Single-Family Graywater Systems

Single-family graywater systems collect drainage from showers, bathtubs, bathroom sinks, and/or clothes washers; store and treat that graywater onsite; and then supply the treated graywater for household water uses such as toilet flushing, clothes washing, and/or irrigation. To assess exposure risks to enteric pathogens, the IAP considered the additional risk of enteric pathogen transmission through reused water compared to the baseline rate of household gastrointestinal illness transmission from other routes within the home (*e.g.*, person-to-person, contaminated objects and surfaces, and existing waterborne pathways). In this context, existing risk models suggest that enteric pathogens are a concern for single-family graywater reuse systems and treatment is required for non-potable use. Additionally, sufficient information exists to indicate an enhanced risk of opportunistic pathogen growth, such as *Legionella* spp., in single-family graywater reuse systems compared to potable water. Factors contributing to this enhanced risk may include storage at elevated temperatures, water age, nutrient content, and low or no disinfectant residual. The IAP concluded that risk-based treatment targets such as LRTs are not appropriate for opportunistic pathogens due to the potential for regrowth following treatment. Therefore, strategies for minimizing opportunistic pathogen growth were suggested including flushing the plumbing system, producing highly disinfected non-potable water that is low in carbonaceous material and nutrient content, maintaining a residual disinfectant level, and/or controlling temperature.

In evaluating single-family water reuse systems, the IAP used the 2017 Water Environment and Reuse Foundation (WE&RF) report *Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems* to guide its risk-based assessment. Although many of the same considerations apply at this smaller scale, some modifications were deemed appropriate based on the IAP analysis. For example, while pathogen log reduction targets (LRTs) presented in the 2017 guidance are also protective for single-family settings, lower targets may be applicable when considering existing levels of enteric pathogen transmission in homes. Such LRTs are available in a recent publication from researchers at Eawag (Swiss Federal Institute of Aquatic Science and Technology), which were utilized to generate numerical recommendations.

The IAP also reviewed existing industry standards including NSF/ANSI 350-2023 *Onsite Residential and Commercial Water Reuse Treatment Systems* and IAPMO/ANSI Z1324-2022 *Alternate Water Source Systems for Multi-Family, Residential, and Commercial Use* for applicability to single-family graywater systems. While NSF/ANSI-350-2023 is not explicitly risk-based, it includes optional LRTs in Annex N-2 for multi-family residential and commercial systems that would also be conservative for single-family homes. However, since certification to meet the LRTs is not applicable to single-family systems, their level of health protection when meeting NSF/ANSI 350-2023 remains uncertain. Similarly, IAPMO/ANSI Z1324-2022 certification is not applicable to single-family systems and therefore, it remains uncertain if a single-family graywater system certified to IAPMO/ANSI Z1324-2022 would be protective of public health without explicit inclusion of appropriate LRTs.

Key Takeaways for Single-Family Graywater Systems:

- Enteric pathogen transmission is a concern, primarily from viruses. A virus LRT of 5.0 is recommended to meet a risk benchmark of 10^{-2} infections per person per year (pppy). This benchmark was assessed based on the IAP's analysis of baseline household transmission rates and is less stringent than the 10^{-4} infections pppy typically associated with drinking water.
- User exposure to opportunistic pathogens and growth of opportunistic pathogens in a single-family graywater reuse system is a concern. Recommended Best

Management Practices (BMPs) to control for opportunistic pathogen growth in larger decentralized systems can be adapted to the single-family scale.

- Fail-safe backflow prevention is important for single-family graywater systems.
- The IAP is recommending that the SFPUC endorse the use of single-family graywater systems which comply with amended NSF/ANSI 350-2023 and/or IAPMO/ANSI Z1324-2022 standards that include the recommended LRTs for the single-family scale and other IAP recommendations.
- While common treatment systems previously considered for graywater reuse (*e.g.*, membrane bioreactors (MBR) with ultraviolet radiation (UV) and/or chlorine disinfection) may be sufficient to meet a virus LRT of 5.0, additional research is needed to identify more energy efficient treatment trains for smaller scale applications such as single-family homes. The IAP is recommending that the SFPUC endorse energy efficient single-family graywater systems.
- Robust monitoring is recommended with the use of sensors to verify treatment efficacy and that the LRT is met. Reuse water should be automatically diverted during out of specification conditions or when maintenance activities are not performed.
- Ongoing management and maintenance of installed systems is critical to their risk mitigation performance. Routine maintenance must be performed by the homeowner or via a maintenance contract to ensure single-family graywater systems are managed properly. To promote appropriate maintenance practices, rebates and warrantees can be linked to user training, service packages and/or regular upkeep requirements.
- Information about the single-family graywater system must be disclosed to new homeowners or renters.

Recirculating Clothes Washers

Recirculating clothes washers allow users to recycle water from the rinse portions of the laundry cycle. Rinse water is stored and treated between laundry cycles. Recirculating clothes washers are similar to single-family graywater systems because they store, treat, and reuse graywater onsite. The key difference is that the source water and end use are restricted to clothes washing. Hypothetical appliances that do not store water between uses were considered similar in risk profile to conventional washing machines and beyond the scope of the IAP analysis.

Similar to single-family graywater systems, the IAP assessed the additional risk compared to the general risk of transmission of enteric pathogens in a single-family household. The IAP considered that pathogens from one laundry load could contaminate the water used in the next, potentially exposing different users. Although their limited end use for clothes washing only results in lower estimated exposure volumes, the level of treatment required for recirculating clothes washers is also driven by virus removal. The IAP also found sufficient information to indicate an enhanced risk of opportunistic pathogen growth, such as *Legionella* spp. or *Pseudomonas* spp., when storing water for recirculating clothes washers as compared to conventional clothes washers, particularly when considering the potential for long residence times between use. The IAP concluded that risk-based treatment targets such as LRTs are not appropriate for opportunistic pathogens due to the potential for regrowth following treatment. *Legionella* spp. and other pathogens that can be transmitted through inhalation pose less of a risk in the case of clothes washers (*e.g.*, relative to showers) due to fewer opportunities for users to be exposed to aerosols. However, dermal exposures to opportunistic pathogens that cause skin infections (*e.g.*, *Staphylococcus aureus* and *P. aeruginosa*) are also possible. Similar treatment and operational guidance for single-family graywater reuse systems can be applied to recirculating clothes washers that include storage of laundry water (albeit with a different LRT), given their operational similarities.

Similar to the other single-family water reuse applications evaluated in this report, the IAP looked for existing industry guidance and standards applicable to recirculating clothes washers. The IAP found that currently there are no existing standards for recirculating clothes washers. If the marketplace for recirculating clothes washers further develops, the IAP recommends that a certification standard be developed for this application in accordance with the IAP recommendations.

Key Takeaways for Recirculating Clothes Washers:

- Recirculating clothes washers are similar to single-family graywater systems in that they collect, treat, and store water for later use. Therefore, the same recommendations for enteric and opportunistic pathogen control apply. Using the risk benchmark of 10^{-2} infections pppy, in this case the virus LRT is 3.0.
- Fail-safe backflow prevention is important for recirculating clothes washers.
- Recirculating clothes washers without storage, *i.e.*, reusing water within the same load, are considered comparable in exposure risks to conventional (non-recirculating) washers and were not included in the analysis.
- Robust monitoring is recommended with the use of sensors to verify treatment efficacy and that the LRT is met. Reuse water should be automatically drained

instead of recirculated during out of specification conditions or when maintenance activities are not performed.

- To promote appropriate maintenance practices, rebates and warrantees can be linked to user training, service packages and/or regular upkeep requirements.
- Currently there are no existing standards for recirculating clothes washers. If the marketplace for recirculating clothes washers further develops, the IAP recommends that a certification standard be developed for this application in accordance with the IAP recommendations.
- Information about the recirculating clothes washer must be disclosed to new homeowners or renters.

Recirculating Showers

Recirculating showers recycle water during a shower. Water used during the shower is collected from the floor drain or water collection tank, treated, and then released from the showerhead during a single showering event. Reuse water is generally not retained or stored between showers. Recirculating showers differ from single-family graywater systems and recirculating clothes washers in that water is not stored between uses of the shower and that exposure only occurs to the same individual using the shower.

The IAP was not tasked with evaluating specific products available in the market; however, three recirculating shower manufacturers provided an overview of system operating principles for informational purposes only. This report does not validate or refute manufacturer claims regarding recirculating showers which are available in the marketplace and/or proposed for the marketplace.

The IAP determined the primary concern for recirculating showers is an enhanced risk of opportunistic pathogen growth, such as *Legionella* spp., compared to conventional showers because organic matter and non-microbial contaminants such as soap and shampoo are present in the recirculated water and may lead to biofilm and opportunistic pathogen growth in the drain, piping, showerhead, and other system components. Furthermore, aerosol generation via showers is a known exposure pathway for legionellosis cases, and the lower quality of recirculated water relative to potable water may exacerbate this risk. High aerosolization rates and enhanced face immersion also differentiate recirculating showers from bathtubs and hot tubs where users are likewise exposed to their own bathing water. The IAP concluded that risk-based treatment targets such as LRTs are not appropriate for opportunistic pathogens due to the potential for regrowth following treatment. Therefore, the IAP identified several recommendations to control the growth of opportunistic pathogens, including treatment to reduce dissolved organics, cleaning cycles between uses, and best management practices for the control of microbial growth.

The IAP identified additional concerns, including infections caused by skin-associated bacteria and enteric pathogens, and the IAP is recommending precautionary treatment to address these risks. At a minimum, the IAP is recommending the use of NSF/ANSI 55 Class A validated UV reactors, which are designed to be used for treating water of unknown quality. Recirculating showers should also include adequate pretreatment prior to the UV, including solids and dissolved organics removal. The IAP is recommending that filtration standards appropriate for treatment of non-potable water be identified and/or specific water quality limits (*e.g.*, biological oxygen demand (BOD), total suspended solids (TSS), heterotrophic plate count (HPC), turbidity) be defined. Online monitoring or local sensors should be used to ensure that the water entering the UV reactors meets reactor specifications.

In addition to evaluating the appropriate risk management approaches, the IAP reviewed existing industry guidance, which consisted of the IAPMO IGC 330-23 *Industry Standard for Recirculating Shower Systems*. IGC 330-2023 does not refer to removal requirements for pathogens or specify a need to manage biofilm growth or opportunistic pathogens, with the exception of the drain test. The IAP identified the need for specific modifications to IAPMO IGC 330-23 to incorporate the IAP's treatment recommendations and address gaps related to testing procedures and user awareness.

Key Takeaways for Recirculating Showers:

- The primary concern for recirculating showers is an enhanced risk of opportunistic pathogen growth, such as *Legionella* spp., compared to conventional showers.
- Risks of infections caused by skin-associated bacteria, enteric pathogens, and autoinfection were not quantitatively assessed but are also of concern. UV disinfection can address these concerns.
- Use of a validated reactor (NSF/ANSI 55 Class A) with adequate pretreatment prior to the UV is recommended. Online monitoring or local sensors can be used to ensure that the water entering the UV reactor meets reactor specifications.
- The reduction of dissolved organics is necessary to ensure the safe operation of the recirculating shower system and the effectiveness of disinfection.
- Implementation of dissolved organics removal, cleaning cycles, and best management practices are recommended to control growth of opportunistic pathogens.
- Fail-safe backflow prevention is important for recirculating showers.

- Immunocompromised individuals or those with respiratory diseases are at a higher risk of negative health outcomes from opportunistic pathogens. The IAP recommends that individuals using recirculating showers consult one's doctor if they have skin issues, open wounds, and/or are immunocompromised.
- The IAP identified the need for specific modifications to IAPMO IGC 330-23 to incorporate the treatment recommendations and address gaps related to testing procedures and user awareness. An associated certification process should be developed to demonstrate that systems meet these criteria.
- The IAP recommends that the SFPUC endorse the use of recirculating showers which comply with an amended IAPMO 330-2023 that is consistent with recommendations by the IAP.
- To promote appropriate maintenance practices, rebates and warrantees can be linked to user training, service packages and/or regular upkeep requirements.
- Information about the recirculating shower system must be disclosed to new homeowners or renters.
- Outside the U.S. there may be other applicable water quality standards that are not covered in this report.

Operation and Maintenance

Monitoring and maintenance of all single-family home water reuse systems are essential for reliably safe use. It is assumed that the homeowner is responsible for operation and maintenance. To ensure continuous function of water reuse systems, simple periodic maintenance tasks will be necessary, as well as automatic system shutoffs if water quality checks fail or maintenance tasks are not performed. This can be achieved using online monitoring or local sensors and selection of treatment processes for which such technologies exist. The IAP recommends that rebates and manufacturer warranties be linked to maintenance and monitoring requirements to promote such practices. Rebates should be contingent on an initial training of the users of potential risks, proper use, and maintenance, as well as subscriptions to maintenance packages. Annual reporting can be used to evaluate success of the overall reuse program and whether public health requirements are met in real-world practice. Upon the sale of a dwelling, water reuse systems and appliances must be disclosed to the new owner or renter and trainings, rebates, and maintenance packages should be made accessible.

Key Takeaways for Operation and Maintenance:

- It is recommended to use continuous monitoring systems or local sensors to monitor system performance for all single-family home water reuse systems. As with other onsite water reuse systems, online monitoring of performance surrogates correlated with pathogen LRT requirements appropriate for each unit process is recommended.
- Reuse water should be automatically drained instead of recirculated during out-of-specification conditions or when maintenance activities are not performed.
- To promote appropriate maintenance practices, rebates and warrantees can be linked to user training, service packages and/or regular upkeep requirements. Annual reporting can be used to evaluate ongoing performance of the water reuse program and the extent to which public health recommendations are practically achieved. The IAP recommends that if the SFPUC encourages the implementation of single-family graywater systems, recirculating clothes washers, and/or recirculating showers, a policy should be adopted that the system be disclosed upon sale of the home and information related to applicable rebate conditions provided (*e.g.*, the new homeowner should be given access to training and maintenance subscription packages). If a single-family home is occupied by renters, the owner should be responsible for the system maintenance.
- IAP suggests that labeling identifying the possible risks and a source for operational procedures should be provided on single-family water reuse units.

Costs and Life Cycle Impacts

Due to economies of scale, single-family graywater systems and recirculating clothes washers may not be energy or cost effective when using current technology recommendations (*i.e.*, MBRs). However, recirculating showers may have potential for lowering overall energy requirements due to their reductions in hot water heating.

IAP Recommendations

The IAP makes the following technical and policy recommendations:

Technical Recommendations:

- Amend IAPMO 330-2023 standard to address IAP public health concerns prior to advancing implementation of recirculating showers on a wide scale. Several members of the IAP are involved in the IAPMO Technical Subcommittee for the standard amendments, which is currently underway.
- Amend NSF/ANSI 350-2023 standard to reflect IAP recommendations, including optional LRTs for single-family residential settings in accordance with those recommended by the IAP. Members of the IAP are engaged with NSF on this topic.

- Amend IAPMO/ANSI Z1324-2022 standard to reflect IAP recommendations, including LRTs applicable to the single-family scale in accordance with those recommended by the IAP.

Policy Recommendations:

- Encourage recirculating showers when IAPMO 330-2023 is satisfactorily amended in accordance with the IAP recommendations.
- Encourage single-family graywater systems when NSF/ANSI 350-2023, IAPMO/ANSI Z1324-2022, and other relevant industry standards are amended to include the recommended LRTs for the single-family scale and other IAP recommendations.
- If the marketplace for recirculating clothes washers further develops, the IAP recommends that a certification standard be developed for this application in accordance with the IAP recommendations.
- Require validated minimum virus LRTs of 5.0 and 3.0 for single-family graywater and recirculating clothes washers (with storage of graywater), respectively. Online monitoring systems or local sensors can be used to ensure ongoing system performance.
- Encourage single-family graywater systems that are energy efficient.
- Rebates for single-family dwelling reuse appliances should meet the following conditions:
    - Treatment and BMP recommendations are followed;
    - Training is provided on potential risks, proper use, and maintenance;
    - A subscription to a maintenance package is obtained (rebates could cover annual maintenance packages);
    - Upon sale of the dwelling, the new dwelling owner should be made aware of the water reuse appliance and follow the conditions of the rebate if the system will continue to be used; and
    - An annual report or evaluation be provided by the user that includes items such as customer experience, ease of use, reliability, frequency of maintenance, frequency that the reuse mode was utilized, and estimated water savings.

1 INTRODUCTION

Water is a defining issue of our time. Cities across the world are rethinking the traditional approach to water systems in the face of drought, extreme weather, and associated impacts on water quantity and quality. Use of alternative water sources for a range of potable and non-potable end uses is increasingly employed at a variety of scales. The National Alliance for Water Innovation recently identified small-scale, distributed treatment systems as one of the largest opportunities for reuse given avoided energy and infrastructure costs related to transporting water to and from centralized facilities (Sedlak, 2021).

San Francisco recognized the opportunity to build and manage its city to be more resilient with localized (*i.e.*, decentralized) water treatment systems. In San Francisco, onsite water treatment systems are required in large multi-family and commercial buildings. The onsite treatment systems capture graywater or blackwater for non-potable reuse such as toilet flushing and irrigation. Critical to the success of its onsite water recycling program was the development of treatment guidance (*i.e.*, $\log_{10}$ reduction targets, or LRTs), critical control point monitoring, and an oversight program to maintain protection of public health in San Francisco.

The SFPUC is looking to expand the possibility of reusing or recirculating water onsite with additional technologies, such as household graywater systems, recirculating clothes washing machines, and recirculating showers. Fixtures and appliances are already available in the marketplace today, such as single-family graywater systems and recirculating showers, and considerations of new technologies to recirculate clothes washing water are underway.

With respect to onsite water reuse, the SFPUC's top priority is to prevent infections and illnesses associated with exposure to reused or recirculated water, while remaining cognizant of issues related to both operation/maintenance and life cycle costs/impacts. The SFPUC established an IAP of research experts to assess reuse applications in single-family dwellings and to assess public health considerations, treatment needs, and best management practices for these systems. This IAP report provides technical and policy recommendations for implementing fixtures and appliances such as household graywater systems, recirculating clothes washing machines, and recirculating showers in San Francisco. The IAP was not tasked with evaluating specific products available in the market; however, three recirculating shower manufacturers provided an overview of system operating principles for informational purposes only. This report does not validate or refute manufacturer claims regarding single family water reuse applications which are available in the marketplace and/or proposed for the marketplace. The IAP consists of experts and leaders in the fields of risk assessment, public health, regulation and policy, sustainable water systems, and engineering.

Onsite reuse, in the context of this project, is for single-family dwellings defined as single-family homes, apartments, or condominiums in which a small unit of persons reside together, typically around five individuals for consistency with past risk assessments. These single-family dwellings represent high-risk settings for enteric pathogen transmission, given the close proximity of residents, high levels of interaction, and shared use of common spaces and fixtures. The IAP evaluated the risk of enteric pathogen transmission through reused water in single-family dwellings relative to the baseline risk of illness transmission in the dwelling from person-to-person contact, contaminated objects and surfaces, and existing waterborne pathways. The IAP also evaluated opportunistic pathogen concerns and considered the potential impacts of various operation and maintenance practices.

2 OVERVIEW OF SINGLE-FAMILY WATER REUSE APPLICATIONS

At the household level, there is a potential for additional water savings with appliance scale recirculation for showering and laundry. Table 2.1 summarizes potential water savings for different residential end uses, which estimates up to a 50 percent reduction in water use from recirculating clothes washers and up to an 80 percent reduction in water use from recirculating showers.

These estimates represent the theoretical maximum amount of water savings and actual water savings may be lower depending on the specific product, operation and maintenance and pathogen controls.

Technologies to treat graywater from single-family dwellings are currently available in the U.S. marketplace. Technologies to recirculate shower water are currently available in the U.S. marketplace, but not widely implemented. Considerations of new technologies to recirculate clothes washing water are underway. Actual water savings from single-family dwelling water reuse appliances will depend on product manufacturer and which end-uses are included.

IAP Assumed Operating Principles

For this report, the IAP has assumed the operating principles for single-family graywater systems, recirculating showers, and recirculating clothes washers described below and illustrated in Figures 2.1-2.3.

Single-Family Graywater Systems Assumed Operating Principles:

- Graywater is collected from showers, bathtubs, bathroom sinks, and clothes washers.
- Graywater is treated and stored onsite for reuse.
- End uses for treated graywater include toilet flushing, clothes washing, and/or irrigation.

Table 2.1 SFPUC Potential Estimates to Reduce Water Use in Single-Family Dwellings with Recirculating Technologies

Residential End Use	Average Use per Day	CA Code or Standard	CA Code / Standard Daily Indoor Use Gallons per Person	Potable or Non-potable Reduction (percent)
Shower(1)	9 minutes	1.8 gallons per minute	16.2	Potable (80%)
Toilet Flushing(2)	4.8 flushes	1.28 gallons per flush	6.1	Non-potable
Faucet(3)	11 gallons	1.2 gallons per minute (bathroom) 1.8 gallons per minute (kitchen)	11	Potable
Laundry(4)	0.3 loads	18 gallons per load (Water Factor 6)	5.4	Non-potable (50%)
Bath(5)	1.5 gallons	N/A	1.5	Potable
Dishwasher6	0.7 gallons	5 gallon per cycle/3.5 gallon per cycle (Federal code)	0.7	Potable
Total gpcd for CA Code			40.9	Potable: 25.2 gallons (61.5%) Non-potable: 15.7 gallons (38.5%)

Notes:
gpcd – gallons per capita per day.
(1) Water Energy Savings Specifications for Conservation Program Measures, Page 10. Reference: DeOreo, W., Mayer, P., Henderson, J., Raucher, B., Gleick, P., Cooley, H., & Heberger. M (2010a). San Francisco Single Family Home Water Use Efficiency Study. Boulder, CO. Aquacraft, Inc.
(2) Calculated from 15 flushes per day per household. Water Energy Savings Specifications for Conservation Program Measures, Page 4. Reference: DeOreo, W., Mayer, P., Henderson, J., Raucher, B., Gleick, P., Cooley, H., & Heberger. M (2010a). San Francisco Single Family Home Water Use Efficiency Study. Boulder, CO. Aquacraft, Inc.
(3) REUS 2016 (was 10.9 in 1999 REUS). Reference: DeOreo, W., Mayer, P., Dziegielewski, B., Kiefer, J. (2016) Residential End Uses of Water, Version 2. Water Research Foundation.
(4) Calculated, 0.91 loads per household (Water Energy Savings Specifications for Conservation Program Measures, Page 16)/ 3.03 pphh (WC Model, Brattle Baseline Demand Tab). 0.91 loads per household reference: DeOreo, W., Mayer, P., Henderson, J., Raucher, B., Gleick, P., Cooley, H., & Heberger. M (2010a). San Francisco Single Family Home Water Use Efficiency Study. Boulder, CO. Aquacraft, Inc.
(5) REUS 2016 (was 1.2 in 1999 REUS). Reference: DeOreo, W., Mayer, P., Dziegielewski, B., Kiefer, J. (2016) Residential End Uses of Water, Version 2. Water Research Foundation.
(6) REUS 2016 (was 1.0 in 1999 REUS)/ Energystar Standard for Dishwashers. Reference for Consumption: DeOreo, W., Mayer, P., Dziegielewski, B., Kiefer, J. (2016) Residential End Uses of Water, Version 2. Water Research Foundation.

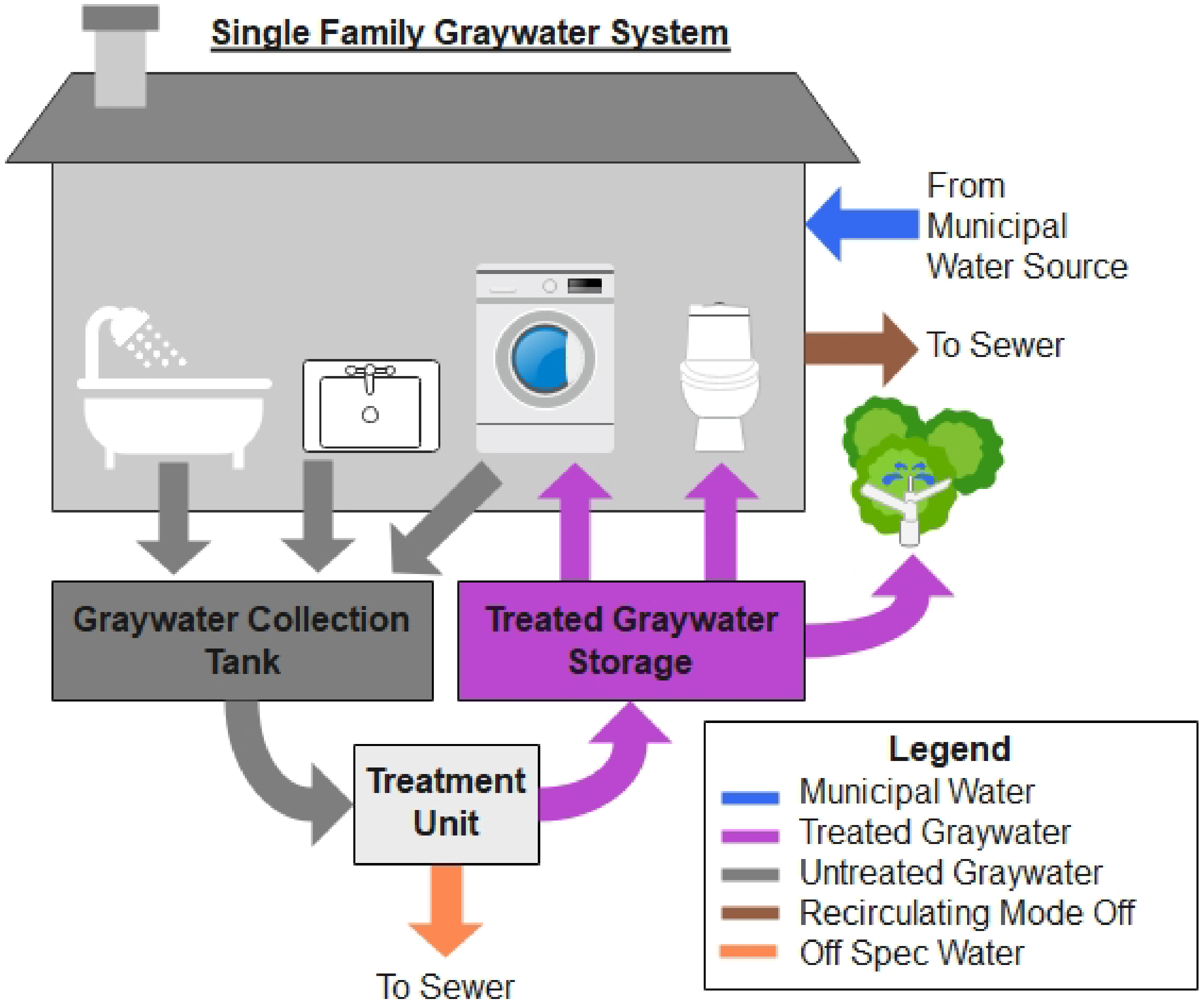


Figure 2.1 Process Schematic for Single-Family Graywater System

Recirculating Clothes Washers Assumed Operating Principles:

- In the context of this analysis, recirculating clothes washers are defined as appliances that store reuse water between laundry loads as illustrated in Figure 2.2. Hypothetical systems that do not store water (*i.e.*, recirculate it within the same laundry load) are operationally similar to conventional washers in that fresh water is utilized to begin each load and that resulting graywater discarded at its conclusion and are not considered in this report.
- Water is collected and treated from the rinse portions of the laundry cycle and stored for reuse in the next wash cycle.
- Users can choose to select potable or recirculated mode.

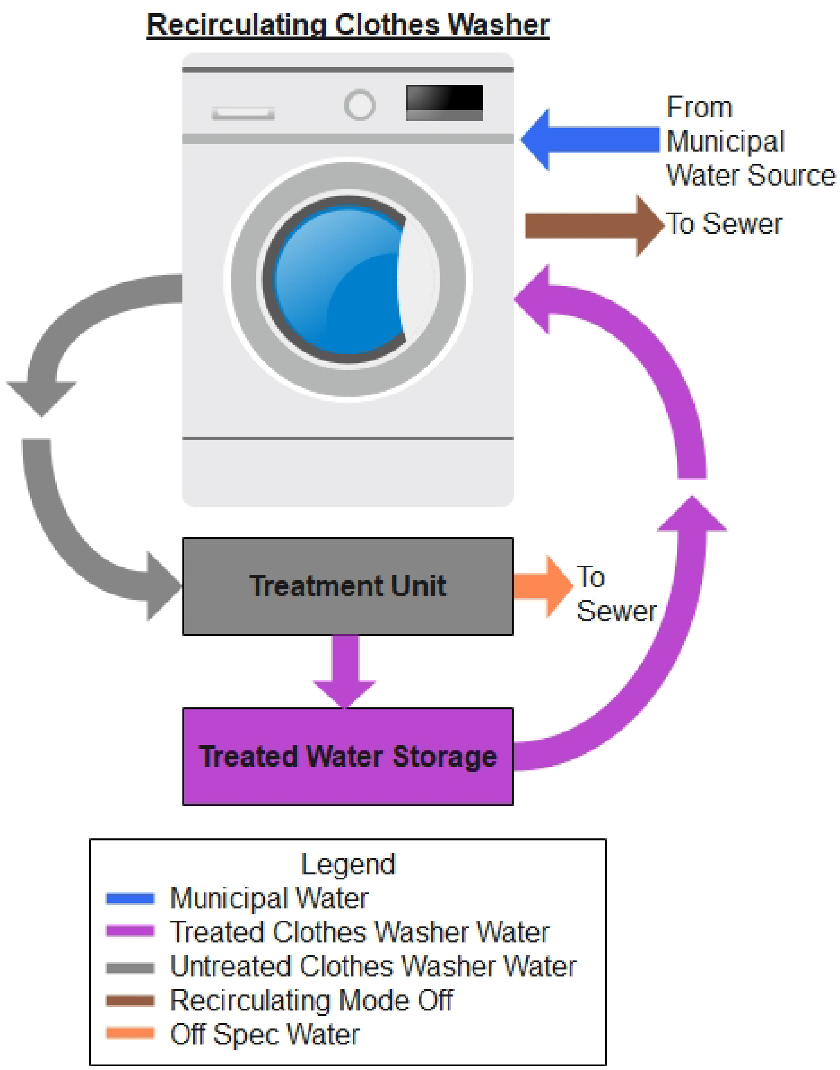


Figure 2.2 Process schematic for Recirculating Clothes Washers

Recirculating Showers Assumed Operating Principles:

- Water is treated and recirculated within a loop during a single shower use and discharged to the drain following the conclusion of the shower as illustrated in Figure 2.3.
- Users can choose to select potable (conventional shower) or recirculation mode.
- Water is recirculated from the floor drain or water collection tank to the showerhead when recirculation mode is selected.
- Reuse water is generally not retained or stored between showers.

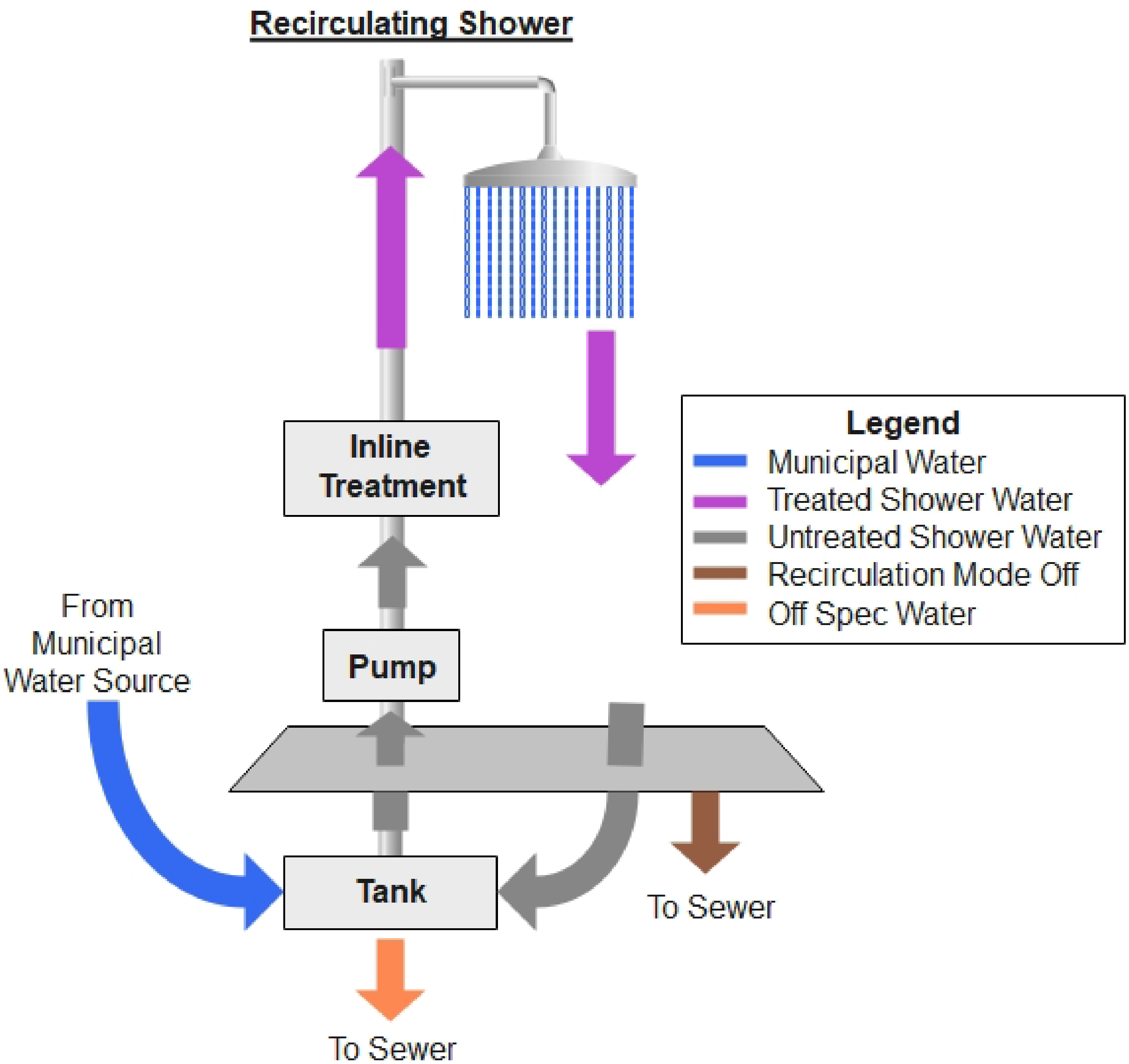


Figure 2.3 Process Schematic for Recirculating Showers

2.1 State of the Science for Single-Family Water Reuse Applications

Established and accepted water quality standards, treatment trains, oversight and management practices, and other policies associated with single-family home applications are not widely available, and there is not yet a broadly accepted set of treatment standards for these systems. To address public health considerations for single-family reuse systems, four studies have been conducted relating to pathogen LRTs considered to be protective of public health. However, it should also be noted that there is limited empirical data available on pathogen occurrence and exposure in these systems and modeling assumptions are made using the best-available scientific information. Outside the U.S. there may be other applicable water quality standards that are not covered in this report.

2.1.1 2017 Water Environment and Reuse Foundation Report

In a WE&RF report, Sharvelle et al. (2017) outlined management practices, treatment targets, and monitoring guidance to support the widespread adoption of decentralized non-potable water (DNW) systems. The proposed framework includes guidance for system design, including LRTs and proposed treatment process trains, management plans including specifying the responsible management entity (RME) and their roles/responsibilities, permit application report submission, construction and commissioning, operational monitoring of surrogate water quality and/or operational parameters correlated to the LRTs, and reporting. However, the WE&RF report only includes DNW systems at the building, neighborhood, or district scale in its scope, and does not directly address single-family dwelling/appliance scale systems. Nonetheless, there are components of the 2017 guidance that may be applicable to single-family dwellings as outlined below in Table 2.2.

Table 2.2 Potential Application of WE&RF Guidance for Single-Family Dwelling Water Reuse Appliances

2017 DNWS Recommended Component for Large Buildings	Applicability to Single-Family Dwelling/Appliance Scale	Areas where Modification or Expansion is Required for Applicability to Single-Family Dwelling/Appliance Scale
Identify Management Category	This component provides a framework to assess relative risk and need for management and includes direct recommendations for single-family residence applications.	None.
Select LRTs	Appropriate LRTs can also be developed and applied for application at this scale.	2017 LRTs were recommended based on estimate of 1000 persons; therefore, revised LRTs are recommended at single residence scale.
Evaluate Possible Treatment Process Trains to Achieve LRTs	While LRTs could be different, the approach of applying LRTs to identify feasible treatment trains is applicable.	Example treatment process trains designed based on LRTs for single-family residences could be developed. Technologies should be selected for which implementable online monitoring solutions exist.

2017 DNWS Recommended Component for Large Buildings	Applicability to Single-Family Dwelling/Appliance Scale	Areas where Modification or Expansion is Required for Applicability to Single-Family Dwelling/Appliance Scale
Designate RME	The RME guidance provided in the 2017 document is relevant to multi-residential and commercial scale applications and not specific to the single residence scale.	RME will be the dwelling owner.
Develop Monitoring Plan	Robust monitoring linked to system controls is needed for successful implementation.	Online monitoring or local sensors are recommended to be in place to ensure ongoing treatment performance and rapidly detect any system failures.. Pragmatic monitoring plans or local sensors need to be considered at the single-family dwelling scale. For example, weekly or monthly calibration of continuous monitoring devices presents a practical challenge.
Develop Best Management Practices	Best management practices are needed at residential scale to operate system to reduce risk and control opportunistic pathogens.	Approaches most feasible and relevant for single-family residences need to be considered for recommendation.
Reporting Requirements	Frequent routine reporting as recommended in the 2017 guidance is not pragmatic for residence owner or regulating entity. Specific requirements need to be considered and defined.	Some level of reporting is recommended and can be tied to rebate requirements.

Notes: Adapted from Sharvelle et al. 2017.

2.1.2 U.S. EPA, Office of Research and Development Onsite Reuse Research

In support of the WE&RF guidance document (Sharvelle et al. 2017), researchers at the U.S. Environmental Protection Agency Office of Research and Development (EPA-ORD) conducted quantitative microbial risk assessments (QMRA) to determine risk-based treatment targets for decentralized water reuse (Schoen et al. 2017). An underlying concept in this work was that pathogen densities (and hence risk) vary at different wastewater collection scales (*e.g.*, single-family vs. large buildings or districts) due to the sporadic nature of infections among small populations and the varying levels of wastewater dilution offered by non-infected users of the system (as would be expected in larger collections).

To address this question, Jahne et al. (2017) developed an approach to modeling pathogen concentrations in variously sized graywater and combined wastewater collection systems based on epidemiological pathogen incidence rates, user population size, and fecal loadings to various residential wastewater sources. Simulations were used to evaluate three population sizes (5, 100, and 1,000 persons) for seven pathogens on each day of 10,000 possible years. Fecal contamination of fresh graywater from bathroom sinks, showers/baths, and laundry, as well as local wastewater from all sources including toilets was investigated. This approach successfully estimated pathogen loads for larger systems (approximately 1,000 persons), which were demonstrated as reasonable conservative estimates for norovirus via a limited sampling campaign (Jahne et al. 2020). Resulting pathogen characterizations were subsequently used to develop risk-based treatment targets (Schoen et al. 2017) adopted in the WE&RF guidance.

However, at smaller scales (5 persons) population infection rates were sufficiently low that risk targets for most pathogens would be met even without treatment; only norovirus had stable LRTs, which were<1 log lower than the 1,000 person estimates. Schoen et al. (2017) include treatment targets based on two alternative risk benchmarks for the larger scale systems (10^{-4} or 10^{-2} infections pppy); 5 person results were only presented for the 10^{-4} infections pppy metric.

Later work sought to further assess and extend the risk-based models. Of note, Schoen et al. (2020) included new LRTs for ingestion exposure to enteric pathogens during bathing or showering. Since shower/bath behavior is notably variable between individuals (*e.g.*, levels and duration of face immersion, other activities performed, children vs. adults) and lacking data on bathing-specific exposures, recreational water exposure was used as a modeling proxy. LRT results were approximately 1.5 log higher than traditional non-potable uses for the larger systems (100 or 1,000 person); five person LRTs were not calculated, yet would follow the same pathogen occurrence trend noted above. However, these LRTs are not applicable to appliance-scale reuse where the population size is 1 (*i.e.*, the only person contributing to the graywater is the person then using it). Subsequent work (Schoen et al. 2021) developed a risk assessment model for skin pathogens (*Staphylococcus aureus*, including antibiotic resistant strains) during bathing, determining that graywater treatment meeting the shower LRTs would also be protective of this exposure pathway. The group recently published an update to their previous models that incorporates the latest science on pathogen characterization and dose-response (Schoen et al. 2023), which also included an additional health benchmark of 10^{-6} disability-adjusted life years (DALYs).

Additionally, their work found that smaller-scale onsite reuse systems may have greater relative environmental and financial costs, suggesting that such configurations likely suffer from diseconomies of scale (Arden et al. 2021). The paper evaluated four non-potable reuse (NPR) system types: rainwater harvesting (RWH), air-conditioning condensate harvesting (ACH), and source-separated graywater or mixed wastewater membrane bioreactors (GWMBR, WWMBR), in terms of their ability to satisfy onsite non-potable demand, their environmental impacts, and economic cost. To do so, the researchers determined the availability of alternative water sources relative to the non-potable demands of a large building and evaluated the life cycle costs and potential environmental impacts of these onsite NPR systems across a range of building sizes and occupancy rates for the entire U.S.

The general findings of the study were:

- RWH and ACH were only able to satisfy a fraction of non-potable demand even under favorable climate conditions.
- MBR system environmental impacts depended on the composition of the local energy grid.
- WWMBRs were found to have the lowest cost under the largest range of building characteristics and locations, achieving cost parity with local drinking water rates when those rates were more than $7 per 1,000 gallons which could occur in 19 percent of surveyed cities.

2.1.3 Trussell Technologies Single-Family Reuse Memorandum

The SFPUC recently partnered with Trussell Technologies, Inc. to study single-family reuse systems. Trussell's *Evaluation of Single-Family Reuse Systems Technical Memorandum* (2023) established a five-step framework for evaluating treatment requirements for various single-family source waters and end uses and applies the framework to three specific cases including household graywater systems, recirculating washing machines, and recirculating showers. The study addressed exposure from incidental ingestion, contact with skin and mucous membranes, and inhalation of water aerosols, each of which introduces risks from different sets of pathogens that must be considered for control. The report included the development of LRTs and sample treatment trains.

The five steps were:

- Define end uses (toilet flushing, irrigation, shower, etc.)
- Determine exposures (inhalation, ingestion, skin contact, cross connection, etc.)
- Identify relevant pathogens (pathogens associated with each exposure type)
- Quantify exposure (concentration of pathogens, volume of water)
- Develop treatment approach (risk-based treatment goals, management practices, etc.)

LRTs were developed to provide treatment and controls that reduce the risk of infection to 1 in 10,000 infections pppy. Aesthetic concerns such as color and odor were noted as important, in particular for clothes washing applications, and must be considered in addition to pathogens.

Potential interferences to treatment were also identified, including:

- Systems intending to use free chlorine as a disinfectant for pathogen control must ensure that the source water does not contain high levels of ammonia, which would convert free chlorine to the less powerful chloramine species and reduce virus disinfection capability.
- Turbidity and ultraviolet radiation absorbance (UVA) need to be within acceptable limits for ultraviolet radiation (UV) treatment to ensure appropriate dose delivery. UVA also impacts energy use for UV systems to meet a target UV dose.

For the applications considered in this report, treatment trains of MBR followed by UV disinfection and chlorination were proposed as potential treatment solutions. No pathogen removal credit was claimed for the MBR; however, crediting criteria have been developed should this be desired (*e.g.*, WRF 4997) (Salveson et. al, 2021). MBRs also reduce biochemical oxygen demand (BOD) and turbidity that could impact UV disinfection efficacy and contribute to aesthetic concerns. While MBRs may be able to function appropriately for graywater systems they may not be appropriate for recirculating showers due to insufficient time to come to equilibrium (during a shower) and achieve the intended treatment goals (effective microbiological performance will depend upon the organic loading into the MBR). Additional studies would need to be performed to determine the effectiveness of MBRs for recirculating showers.

The general findings of the study were:

- LRTs were recommended for enteric viruses: single-family graywater 8.0; recirculating clothes washers 7.0; and recirculating showers 10.0 – where virus log reduction targets (LRTs) were based on the 95th percentile virus risk to meet an infection target of 10^{-4} pppy.
- Implement best practices for control of opportunistic pathogens by maintaining a chlorine residual (both free chlorine and chloramines have been shown to effectively control *Legionella* spp.).
- Provide monitoring to verify the LRTs are met and achieve other water quality targets adopted from established non-potable reuse guidance.

2.1.4 Eawag Graywater Recycling Study

Eawag has prepared a publication on LRTs for graywater recycling at different collection scales, including appliance-scale reuse of individual graywater sources (Reynaert et al. 2024). The study investigated graywater treatment systems that recirculate water for toilet flushing, clothes washing, hand washing, and showering, as well as clothes washers and recirculating showers. For all systems, the assumption was that water would be recirculated in a closed loop, without discharge between users or usages. The Eawag study investigated the sensitivity of LRTs for incidental ingestion and cross-connection events, including the frequency of events and the fraction of the population affected. For reuse at the scale of a single-family dwelling (5 people), bacteria and protozoa LRTs were typically 0 at the 95th percentile pathogen level in the feedwater. Virus LRTs varied but were typically close to the other studies. For reuse of mixed graywater for indoor applications (including showering), the maximum virus LRT to meet a health benchmark of 10^{-4} infections pppy was 8.6, for recirculating clothes washers 4.8, and for recirculating showers 8.5. However, mixed graywater use included showering which is not included in this IAP assessment of single-family graywater systems. For reuse of mixed graywater only for toilet flushing and clothes washing, the maximum virus LRT to meet a health benchmark of 10^{-4} infections pppy was 6.9, assuming that 10 percent of the population is affected by cross-connections with potable water during 1 day / year (as also assumed in the previous risk assessments above). Note that while virus LRTs are based on molecular measurements of norovirus, pathogen densities were estimated based on fresh fecal shedding by infected individuals and the available dose-response model was likewise developed using genome copies measured in feces. Similarly to the report by Trussell Technologies (2023), treatment technologies using MBR, UV, and chlorination in series were proposed to manage enteric pathogens.

LRTs for 10^{-2} infections pppy were also presented and are approximately 2-log lower than for the 10^{-4} infections pppy benchmark. For systems that treat mixed greywater to be reused for toilet flushing and clothes washing (including the rare cross-connection) and for recirculating clothes washers, respectively, the LRTs were 4.9 and 2.8 to meet a 10^{-2} infections pppy benchmark. The main findings from the study were:

- Separating graywater streams down to appliance-scale reuse can reduce required LRTs for certain applications, such as recirculating clothes washers. However, these reduced LRTs do generally not allow for simpler treatment technologies considering current validated $\log_{10}$ reduction values (LRV) for unit treatment processes (MBR, UV, and chlorine).
- Similarly, reducing the collection scale from large buildings to single-family dwellings does not generally allow for simpler treatment technologies due to high virus LRTs even at small scales. However, graywater reuse at the single-family dwelling scale can allow for simpler treatment technologies if less conservative health benchmarks are used due to a reduced relative importance of treated graywater in pathogen transmission compared with person-to-person transmission in this setting. For a health benchmark of 10^{-2} pppy, virus LRTs are reduced by 2-log.
- Appliance-scale reuse may also allow for simpler treatment technologies in the future if higher LRVs can be validated for unit processes.

2.2 Summary of the Studies

Trussell, EPA-ORD, and Eawag studies each concluded that small scale graywater systems require enteric virus LRTs to protect public health. With the exception of Eawag, which included a 10^{-2} infections pppy benchmark, these were based on a risk target of 10^{-4} infections pppy. All proposed LRTs corresponded to the 95 percent quantiles of LRTs. Consequently, if technologies are designed to exactly meet these LRTs, the infection benchmark is expected to be achieved in 95 percent of years. It should be noted, however, that pathogen log reductions for treatment technologies are often credited based on their low-end performance (*e.g.*, lowest 5 percent during testing), resulting in added conservatism. EPA-ORD also included skin pathogens, finding that treatment for viruses is likely protective for these as well when the water is used for bathing, provided corresponding shower targets are used. However, shower models were not reflective of recirculating showers with a single user. Trussell further highlighted the importance of opportunistic pathogens such as *Legionella* spp., recommending operational practices be implemented to reduce their post-treatment growth. They also acknowledged the need for control of aesthetic concerns and potential interferences during treatment (*e.g.*, ammonia, turbidity, and UVA). Eawag and Trussell both proposed treatment trains consisting of MBR, UV, and chlorine for single-family graywater toilet flushing and clothes washing or irrigation applications meeting the 10^{-4} infections pppy benchmark, with Eawag noting that a lower target or improved LRV validation could result in simpler technologies. These treatment processes are generally the same as for larger scale onsite systems and do not change for recirculating appliances based on their model assumptions, yet Trussell notes that they may be operationally challenging. Finally, EPA-ORD studies suggest that diseconomies of scale may result in high costs and environmental impacts with decreasing system size.

2.3 Current Industry Guidance and Standards for Single-Family Water Reuse Applications

Current industry guidance and standards pertaining to single-family water reuse applications are summarized below.

2.3.1 NSF/ANSI 350

NSF/ANSI 350 was initially published in 2011. This internationally recognized water reuse standard is titled *Onsite Residential and Commercial Water Reuse Treatment Systems*. The standard established minimum criteria for component materials, design and construction, and performance or water quality treatment requirements for onsite residential and commercial water reuse treatment systems. Included in the standard are requirements for essential product information and literature that manufacturers shall supply to authorized representatives and owners as well as the minimum service-related obligations that a manufacturer shall extend to owners. End uses appropriate for the treated effluent discharged from certified onsite residential graywater systems meeting the Class R (single-family residential with flows less than 1,500 gallons per day (gpd)) requirements include indoor restricted urban water use, such as toilet and urinal flushing, and outdoor unrestricted urban water use, such as surface irrigation.

Water quality testing is an integral component of NSF/ANSI 350. The testing schedule runs for 26 weeks during which systems undergoing the certification testing are exposed to 16 weeks of “design flow”, 7.5 weeks of stress flow events followed by an additional 2.5 weeks of design flow. The influent quality is specified in the protocol and includes standard water quality parameters, indicator microorganism counts, and components typically found in graywater (soap, shampoo, conditioner, toothpaste, etc.). The treatment effluent standards are as presented in the Table 2.3.

Table 2.3 Graywater Quality Standards for Residential Treatment Systems

Constituent	Standard	Maximum
BOD_5(1)	10 mg/L	30
TSS(2)	10 mg/L	10
Turbidity	5 NTU	n/a
E. coli (MPN/100 ml)	14	240
pH	6-9	n/a
Storage Vessel Chlorine Residual	0.5-2.0 mg/ L	n/a

Notes:
BOD_5 – 5 day biochemical oxygen demand; mg/L – milligrams per liter; TSS – total suspended solids; NTU – Nephelometric Turbidity Units.

Following publication of the 2017 risk-based guidance (Sharvelle et al. 2017), Schoen et al. (2020) examined whether systems certified to NSF/ANSI 350-2017a would achieve the viral and protozoan LRTs recommended for public health protection. Since no systems certified for residential graywater were identified at the time, the authors also considered technologies certified for residential wastewater or commercial graywater, including aerobic or moving bed MBRs and a recirculating synthetic sand filter with UV disinfection. It was assumed that the MBRs would also utilize chlorine disinfection to meet state requirements, although the certification itself did not include this process. Sufficient performance data to estimate pathogen removal (*i.e.*, of virus and protozoa surrogates) were unavailable for the sand filter, focusing the analysis on MBRs with chlorination for which virus LRVs of 3.0 and 4.0, respectively, were estimated. Coupled with an assessment of forward-simulated risk following the methods of Schoen et al. (2017) (on which the 2017 guidance was based), the study found that the combined system would likely achieve a public health goal of 10^{-2} infections pppy for viral and protozoan reference pathogens but not a more protective 10^{-4} pppy benchmark (depending on the selected virus dose-response model) when treating residential graywater. However, given that systems seeking certification may use different technologies (other than MBRs) that have varying levels of pathogen removal; that chlorination was not required for the certification itself; and that viral and protozoan removals drive risk yet are not measured during the testing process, it was concluded that certification to NSF/ANSI 350-2017a may be insufficient to meet risk-based public health goals (Schoen et al. 2020).

To address this issue, NSF/ANSI 350-2023 was published in April 2024 that updated the standard to incorporate the risk-based framework in Annex N-2, including LRTs for onsite wastewater and graywater. The LRTs are based on the work of Schoen et al. (2023) and utilize a risk benchmark of 10^{-6} disability-adjusted life years (DALY) pppy; for indoor non-potable use of graywater, the LRTs are 7.5, 4.0, and 3.5 for enteric virus, parasitic protozoa, and enteric bacteria, respectively. Annex N-2 is an optional certification for multi-family residential and commercial systems. This means manufacturers can get certified to NSF/ANSI 350-2023 and also have the option to get certified to meet the LRTs in Annex N-2. However, it should be noted that NSF/ANSI 350-2023 Annex N-2 is not applicable to single-family graywater reuse systems. Additional work is underway by NSF to review the standard for applicability to the single-family scale. Although NSF/ANSI 350-2023 Annex N-2 is not applicable to single-family graywater reuse systems, other elements of NSF/ANSI 350-2023 such as the materials, design and construction, and performance requirements and the minimum service-related obligations may still be relevant to the proper operation and maintenance of single-family graywater systems.

2.3.2 IAPMO/ANSI Z1324-2022

The International Association of Plumbing and Mechanical Officials (IAPMO) created the standard IAPMO/ANSI Z1324-2022 for *Alternate Water Source Systems for Multi-Family, Residential, and Commercial Use* (IAPMO, 2022). This standard covers systems intended to process water from alternate water sources such as graywater, rainwater, stormwater, air conditioning condensate, and other non-potable reuse applications not specifically listed, for use in subsurface and/or surface irrigation, cooling tower makeup and toilet/urinal flushing applications, or other similar reuse applications and specifies requirements for materials, physical characteristics, performance testing, and markings. The standard includes rigorous testing and creates an avenue for systems to achieve third-party certification.

IAPMO/ANSI Z1324-2022 includes risk-based LRTs for graywater systems installed in large commercial and multi-family residential buildings. However, it should be noted that the standard does not include LRTs for the single-family scale. Nevertheless, other elements of IAPMO/ANSI Z1324-2022 such as design, markings, and backflow protection may still be relevant to the proper operation and maintenance of single-family graywater systems.

2.3.3 IGC 330-2023

IGC 330-2023 *Industry Standard for Recirculating Shower Systems* details a number of construction material and related building standard requirements, and also a requirement for filtration and disinfection (IAPMO, 2023).

IGC 330-2023 includes a basic operation and drain test procedure designed to ensure that water reservoirs shall fully drain leaving only as much residual water as a typical shower pan. It is assumed the intent behind this test is to minimize potential for biofilm growth and hence opportunistic pathogens. In addition, the standard includes a procedure for visual inspection of a recirculated mix of soap, shampoo, dirt, and body wash. A pass of this test requires no observation of sediment, color, or odor after recirculation.

IGC 330-2023 does not refer to removal requirements for pathogens or specify a need to manage biofilm growth or opportunistic pathogens, with the exception of the drain test.

2.4 Focus Area for Independent Advisory Panel

The purpose of the IAP is to assess public health considerations, treatment needs, and best management practices for single-family water reuse applications. The IAP report includes technical and policy recommendations for single-family graywater systems, recirculating clothes washers, and recirculating showers to protect human health.

The IAP was tasked with:

- Reviewing scientific literature pertaining to risk management for single-family and appliance-scale reuse;
- Describing public health considerations;
- Considering appropriate risk management approaches for single-family water reuse applications given other exposure pathways for disease spread in the household;
- Assessing increased risks from, and need for mitigation of, opportunistic pathogens (*e.g.*, *Legionella* spp.) if lower health benchmarks and reduced treatment are implemented at the household level;
- Identifying treatment considerations;
- Operation of single-family graywater systems, recirculating clothes washers and shower appliances;
- Validation and/or certifications of water reuse applications;

- Life cycle costs and environmental impacts (*e.g.*, energy and water use) of household scale implementation of recycling relative to larger scale decentralized approaches.

The IAP was not tasked with evaluating specific products available in the market; however, three recirculating shower manufacturers provided an overview of system operating principles for informational purposes only. This report does not validate or refute manufacturer claims regarding single family water reuse applications which are available in the marketplace and/or proposed for the marketplace.

3 ADDRESSING RISKS FROM SINGLE-FAMILY WATER REUSE APPLICATIONS

Single-family graywater systems, recirculating clothes washers and recirculating showers were evaluated based on the following considerations:

- level of concern associated with pathogenic enteric viruses, bacteria, and protozoa;
- opportunistic pathogens;
- operations and maintenance activities;
- other associated risks.

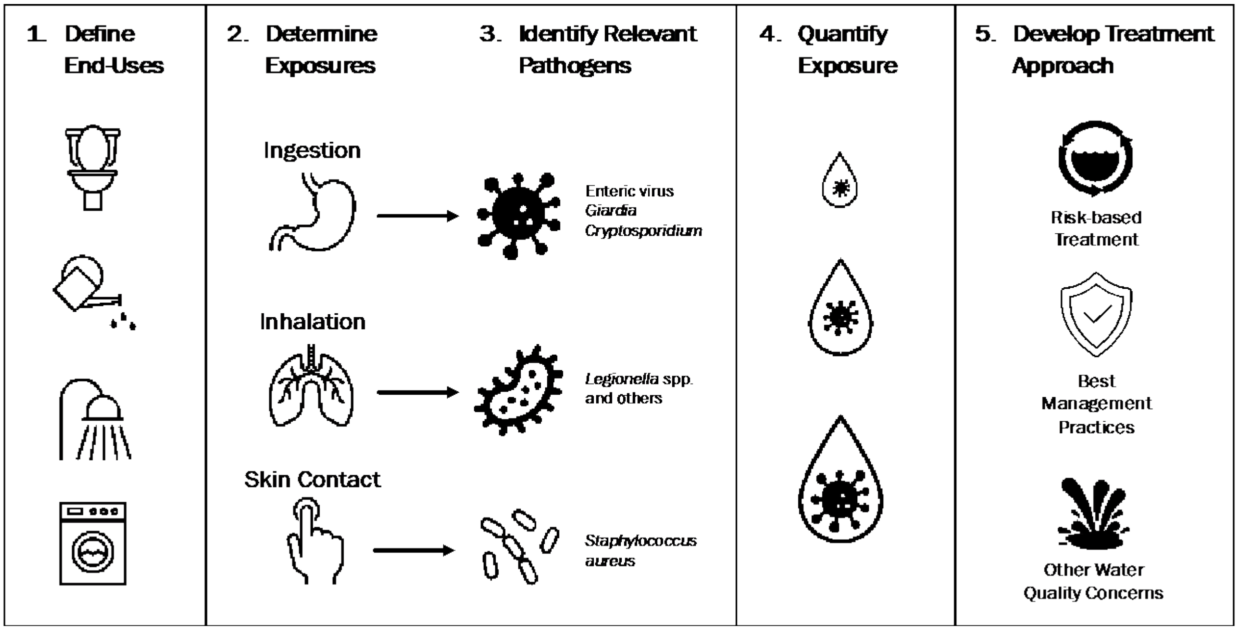
The risk level associated with each concern varies between applications, as outlined in Table 3.1. Additionally, Table 3.1 indicates the general types of guidance that would be relevant to address these concerns; this does not imply that the stated examples are indeed applicable or currently recommended.

Table 3.1 Key Risks of Concern Associated with NPR Applications

Application	SFH Graywater System	Clothes Washer with Storage	Recirculating Shower
Enteric Pathogens	Yes	Yes	NSD(1)
Opportunistic Pathogens	Yes	Yes	Yes
O&M Concern?	Yes	Yes	Yes
Relevant Guidance Type	2017 Risk-based framework/NSF 350 Guidance	2017 Risk-based framework/NSF 350 Guidance	IAPMO Standards

Notes:
NSD - not sufficient data to assess.

The IAP referred to the framework developed by Trussell Technologies (2023) for pathogen exposure pathways and treatment approaches for water reuse applications. As shown in Figure 3.1, the framework outlines the relevant exposure routes, pathogen risks, and treatment approaches for each water reuse application based on the associated end uses.



Adapted from Trussell Technologies (2023).

Figure 3.1 Framework for Pathogen Exposure Pathways and Treatment Approaches for Onsite NPR Systems.

3.1 Enteric Pathogen Management

Quantitative risk-based approaches to water reuse specify a target health benchmark that systems are designed to achieve. This approach assumes that risks to human health cannot be entirely eliminated but can be controlled to be consistent with a selected acceptable risk level. The previous guidance for larger-scale onsite non-potable water systems considered two such benchmarks for enteric pathogens: 10^{-4} (1:10,000) or 10^{-2} (1:100) infections pppy (Sharvelle et al. 2017). The 10^{-4} infections pppy benchmark was used as a reference point during the development of the U.S. EPA's Surface Water Treatment Rule and is the risk basis for California's proposed potable and non-potable water reuse programs (Olivieri et al. 2021, SWRCB 2019). The 10^{-2} infections pppy benchmark has been considered similar to the U.S. EPA's Recreational Water Quality Criteria targets of 32:1,000 or 36:1,000 gastrointestinal illnesses per person per event (U.S. EPA 2012), conservatively assuming that all infections lead to illness and translated to an annual basis (Schoen et al. 2017). The two benchmarks were included to provide risk managers with a range of targets from which to select on the basis of their relevant risk perceptions and decision preferences (Sharvelle et al. 2017).

While a variety of approaches can be used to characterize "acceptable risk", a key point of reference is the baseline risk that the exposed population already tolerates, with the idea that tolerated risks may roughly translate to acceptable risk levels (LeChevallier and Buckley 2007). For example, one proposed justification for the 10^{-4} infections pppy benchmark is that it roughly equated to the per capita number of waterborne illness cases in the U.S. at the time of development (Bennett et al. 1987, Regli et al. 1991, Sinclair et al. 2015). Likewise, the U.S. EPA's targets for recreational water are based on observed illness rates during epidemiological studies to which the water quality criteria are tied (U.S. EPA 2012). These assessments were conducted at the population level (vs. household), where waterborne exposures are a likely route of transmission. It should be noted that while this approach has historical precedence, tolerated risks and acceptable risks may not be interchangeable from an ethics point of view (*i.e.*, a risk may be tolerated because there are barriers to reducing risks to a given target or acceptable level) (Shrader-Frechette 1985). However, it remains a practical way of understanding how risks from new technologies quantitatively compare against current conditions to guide treatment goals.

Single-family dwellings represent high-risk settings for enteric pathogen transmission, given the close proximity of residents, their high level of interaction, and their shared use of common spaces and fixtures. In the context of single-family dwellings, the IAP assessed the additional risk of enteric pathogen transmission through reused water compared to the baseline rate of household gastrointestinal illnesses transmission from other routes within the home (*e.g.*, person-to-person, contaminated objects and surfaces, and existing waterborne pathways). This concept is exemplified by the "relative source contributions" that are considered in chemical risk assessments for drinking water regulations (U.S. EPA 2023).

Following this principle, the IAP estimated the percent increase in household illness transmission that would be attributable to water reuse relative to the existing baseline when meeting previous risk benchmarks (*i.e.*, 10^{-4} or 10^{-2} infections pppy). To do so, the benchmarks were first converted to represent illness based on the reported range of conditional probabilities of illness given infection for relevant enteric pathogens (Gitter et al. 2023). Since the risk-based targets account for the probability of an infected individual using the system, existing estimates of household gastrointestinal illness transmission (*i.e.*, within-household secondary attack rate) for relevant enteric pathogens (Smoll et al. 2021, Perry et al. 2005, Marsh et al. 2018, Alfano-Sobsey et al. 2012, Quee et al. 2012, Balachandran et al. 2023, Parrón et al. 2019) were coupled with associated community gastrointestinal illness rates reported by the U.S. Centers for Disease Control and Prevention (Collier et al. 2021) to calculate a net likelihood for comparison (*i.e.*, the probability of an infected person using the system and then transferring that illness to others in the household). A Monte Carlo simulation (100,000 iterations) was used to incorporate variability and uncertainty in parameter estimates (Table 3.2).

As shown in Table 3.2, the analysis suggests that household-scale reuse following the available 10^{-2} infections pppy benchmark would result in an estimated 5 percent increase in household illness transmission relative to existing conditions; the 10^{-4} benchmark would result in comparative risks that are 100-fold lower (0.05 percent increase in household illness transmission). The objective of this approach is a transparent communication of the additional risks of gastrointestinal illnesses predicted from using water reuse systems in single-family homes that meet previously used benchmark targets; it is ultimately up to each risk manager which benchmark to select for their applications (*e.g.*, potable water is more commonly associated with the 10^{-4} metric). The IAP utilized the available 10^{-2} infections pppy LRT estimates for this report, noting that these are 95^{th} percentile LRTs which will meet the benchmark at least 95% of the time.

Table 3.2 Additional Risk of Water Reuse Relative to Existing Household Transmission Following Previously-Used Infection Risk Benchmarks

Parameter	Values or Calculation
Previously-used benchmark (infections pppy)	10^{-2} (1:100) or 10^{-4} (1:10,00)
Probability of illness given infection	Uniform(min=0.1,max=0.8)
Annual probability of illness from water reuse (illnesses/person/year)	Previously-used benchmark × Probability of illness given infection
Baseline community illness rate (illnesses/person/year)	PERT(min=0.05,mode=0.1,max=0.15)
Annual number of illnesses in 5-person household	Binomial(size=5,probability=Baseline community illness rate)
Annual probability of illness in 5-person household	Simulated years with annual number of illnesses in 5 person household > 0 / years of simulation
Baseline within-household transmission probability (per event)	PERT(min=0.1,mode=0.2,max=0.4)
Annual probability of illness from household transfer (illnesses/person/year)	Annual probability of illness in 5-person household × Baseline within-household transmission probability
Estimated % increase from water reuse (median (5^{th} - 95^{th} percentiles))	10^{-2} infections pppy benchmark: 5.1% (1.5 – 10.9%) 10^{-4} infections pppy benchmark: 0.051% (0.015 - 0.109%)

3.2 Opportunistic Pathogen Management

The IAP identified opportunistic pathogen control as a significant concern across all three water reuse applications. However, risk-based treatment targets such as LRTs are not appropriate for opportunistic pathogens due to the potential for regrowth following treatment (Falkinham et al. 2015). The IAP recommends using best management practices, such as those outlined in the 2017 Risk-Based Framework (Sharvelle et al. 2017), to mitigate opportunistic pathogen growth within single-family home water reuse applications. Some recommended approaches, such as maintaining a residual disinfectant or cleaning storage tanks, are not practical or applicable for every water reuse application at a single-family dwelling scale. Descriptions of recommended management practices and their applicability to each water reuse application of interest are discussed in respective sections for each technology below (Sections 4-6).

3.3 Chemical Risks

While chemicals are not addressed by the 2017 guidance on residential water reuse (Sharvelle et al, 2017), the IAP noted that there are chemical hazards of concern that should be considered in residential graywater systems. This is not an exhaustive list but, rather, a list of several for which there is literature indicating their potential as hazards in residential graywater systems.

Phthalates: Phthalates are a group of chemicals with a wide application to industrial processes, including use in cosmetics, fragrances, face cleansers, dishwasher detergents, fabric softeners, and dishwasher detergent (Sardar et al. 2019). There is some evidence of negative health outcomes due to phthalate exposure, including impacts on respiratory health, endocrine disruption, and reproductive development (Kay et al. 2013). There is evidence of phthalates on clothing and the potential for laundering to remove phthalates (Gong et al. 2016), indicating the potential for phthalate inputs into water reused from laundry cycles. In a comparison of phthalates detected in laundry water vs. shower water (n=25), higher concentrations were seen for laundry than for shower water (Deshayes et al. 2015). However, this may not be representative due to the small sample size and limited geographical focus of that study (Deshayes et al. 2015). More data are needed to understand differences in phthalate concentrations across devices and the potential sources per device (*e.g.*, phthalates in detergents, clothes, personal care products, etc.) (Deshayes et al. 2015).

Per- and polyfluoroalkyl substances (PFAS): PFAS have broad uses across industries, including in water repellant applications for clothing (Van Der Veen I et al. 2022). PFAS exposure can increase risks for a range of negative health outcomes, including cancer, reproductive and developmental issues, kidney disease, and thyroid disfunction (Fenton et al, 2021). Washing, drying, and aging can impact how these chemicals are released from fabrics over time (Van Der Veen I et al. 2022), with the potential for PFAS chemicals to enter graywater systems (Foster et al. 2022). The U.S. EPA has set maximum contaminant levels (MCLs) for perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) at 4 parts per trillion, with a goal of zero, since there is no safe level of exposure to carcinogens (U.S. EPA 2024). Understanding how to control PFAS in recycled water, and all water generally, is ongoing as detection and treatment technologies improve (Kurwadkar et al. 2022).

Xenobiotic organic compounds: Xenobiotics are anthropogenic compounds that include groups such as PFAS. Other groups include polycyclic aromatic hydrocarbons (PAH), pesticides, polychlorinated biphenyls (PCB), and polybrominated diphenyl ethers (PBDE), with a broad range of associated health hazards. These compounds can be present in detergents and other household sources and have been detected in both shower and laundry machine water (Van De Walle. 2023), including detection of pharmaceutical drugs and herbicides (Eriksson et al. 2003; Craddock et al. 2020). While the detection of these compounds identifies them as potential hazards, the risks from anticipated exposure levels in graywater systems are unknown.

Hazardous pharmaceutical compounds: Some pharmaceutical compounds may be especially hazardous if others come into contact, such as those used to treat cancer. Hazardous pharmaceutical compounds are excreted in urine and feces and have been detected on patient bathroom floors in ambulatory settings (Eisenberg et al. 2021). Urination and rinsing of fecal material in showers or in washing machines connected to graywater systems could be a pathway in which household members are exposed to hazardous pharmaceutical compounds from another household member, although to our knowledge no published research has been done on this topic to date. This area requires further research.

Hormones: Hormone therapies may transfer to clothing, depending upon how the hormone is taken or applied. For example, testosterone solutions may be applied to armpits and subsequently transferred to clothing and removed during laundering (Satonin et al. 2016). The influence this may have on graywater originating from laundry machines is unknown. Potential risks from exposures to these chemicals in subsequent graywater contact for prepubertal children should be noted (García & Jiménez. 2017). However, whether concentrations of these chemicals in graywater would pose notable risks for household members is unknown and an area that requires future research. Estrogen or estrogenic compounds could also be present in graywater systems, originating from a number of sources within the home, including excretion in urine, with especially high excretion levels from pregnant individuals (Wise et al. 2011). Ways in which urine may enter a graywater system, such as urination in showers or urine on clothing that is then washed in a reuse washing machine, are not well characterized. Like other hormones, the potential concentrations of estrogenic compounds in graywater and risks for subsequent health outcomes are unknown and require further research (Wise et al. 2011).

Microplastics*:* Primary microplastics originate from small plastic particles in personal care products, textiles, tires, or other products, or their derivatives that enter the environment. Secondary microplastics originate from the breakdown of larger plastics entering the environment (Tang et al. 2024). EPA researchers define microplastics as plastic particles ranging in size from 5 mm to 1 nm (USEPA 2024). Their toxicity is impacted by their size and shape, the microorganisms that sorb to their surfaces, and the chemicals in and around them. Microplastics and their leached compounds are associated with oxidative stress, as well as disruptions of metabolism, gut microflora and gastrointestinal function, cardiopulmonary, immune, endocrine and/or reproductive systems (Tang et al. 2024). Laundry machines are thought to be a significant source of microplastics, primarily due to synthetic clothing (Fontana, Mossotti, & Montarsolo 2020; Napper & Thompson, 2016). Showers can also be sources of microplastics due to fibers, exfoliating microbeads, and other waste materials (Anagnosti et al. 2021; Luo 2022). There is no MCL for microplastics but there are MCLs for some plastic-associated chemicals in California (California State Water Resources Control Board, 2020). Conventional wastewater treatment plants can reduce but not completely remove microplastics (Singh, Kalyanasundaram, & Diwan 2021; Nasir et al. 2024). Threshold Microplastics Concentrations for 10 and 100 µm microplastics of 1748 and 17.5 microplastics/L in drinking water have been proposed (Chowdhury et al. 2024). A lack of quantitative risk assessment approaches has been highlighted as a research gap.

While these considerations raise concerns and highlight risk-risk tradeoffs associated with graywater systems, where a new technology or intervention reduces risk in one outcome (*e.g.*, water scarcity) while raising risk in another (*e.g.*, increased chemical exposure), these risk-risk tradeoffs are inherent in public health. Further, the incidental exposure to small volumes of water during non-potable uses (*e.g.*, toilet flushing and clothes washing) may result in low chemical doses, and treatment processes to manage microbial contaminants may also address some chemical concerns. However, it should be noted there are no data to date that comprehensively and quantitatively compare a wide range of both chemical and microbial health risks for the scenarios relevant to single family water reuse. More research is needed to define the range of exposures expected across different water reuse household uses to better define how chemical risks should be considered in future water reuse recommended requirements and best practices. The previous guidance for larger onsite reuse systems also acknowledged these uncertainties yet considered microbial pathogens to be the greatest concern to human health (Sharvelle et al. 2017).

3.4 Other Considerations

Aesthetic concerns, such as taste and odor, are beyond the scope of this report. Manufacturers may choose to adopt aesthetic goals to address consumer preferences. Organic carbon, nutrients, and solids are also not considered beyond their impact on treatment/disinfection efficacy and the control of microbial growth.

Single-family water reuse applications, particularly recirculating showers, may also introduce new physical hazards or magnify existing physical hazards. If pasteurization is adopted as a microbial growth control method, there is a potential scalding risk for users if they are able to come into contact with the heated recirculation system and/or water at sufficiently high temperatures to cause injury. There is also an enhanced electrical risk associated with the additional complexities of water reuse systems, particularly showers in which the user may use electrical controls while wet.

Protection against potential cross-connections in plumbing is important to ensure separation between potable plumbing and any plumbing conveying water treated onsite. Additionally, installation of proper backflow prevention is critical. Fail-safe and/or redundant backflow prevention of recycled water into potable water supply plumbing should be included in all onsite reuse systems. Additional elements such as signage and labeling are important for proper identification of system components and potential physical risks.

3.5 Summary of Addressing Risks from Single-Family Water Reuse Applications

The IAP has the following general conclusions addressing the risks from single-family water reuse applications:

- Enteric pathogen transmission is a concern, primarily for viruses in single-family graywater systems and recirculating clothes washers. LRTs to meet a risk benchmark of 10^{-2} infections pppy are anticipated to result in an approximately 5 percent increase in household gastrointestinal illness transmission.

- User exposure to opportunistic pathogens is a concern. Approaches similar to those in the 2017 guidance for larger systems should be applied for their control.
- While chemicals are not addressed by the 2017 guidance on residential water reuse, there are several chemical hazards of concern that need more research in residential graywater systems, such as phthalates, PFAS, xenobiotics, hazardous drugs, hormones, and microplastics.
- Other considerations, such as aesthetic concerns, appropriate cross-connection control, signage and labeling, and fail-safe and/or redundant backflow prevention of recirculated water into potable water supply plumbing should be addressed.

4 SINGLE-FAMILY GRAYWATER SYSTEMS

Single-family graywater systems collect drainage from showers, bathtubs, bathroom sinks, and clothes washers, store and treat the water on site, and reuse the treated graywater for toilet flushing, clothes washing, and/or irrigation.

The IAP assumed the following operating principles for single-family graywater systems:

- Graywater is collected from showers, bathtubs, bathroom sinks, and clothes washers.
- Graywater is treated and stored onsite for reuse.
- End uses for treated graywater include toilet flushing, clothes washing, and/or irrigation.

The IAP referred to the framework developed by Trussell Technologies (2023) for pathogen exposure pathways and treatment approaches for graywater treatment systems. As shown in Figure 4.1, the framework outlines the relevant exposure routes, pathogen risks, and treatment approaches for single-family graywater systems.

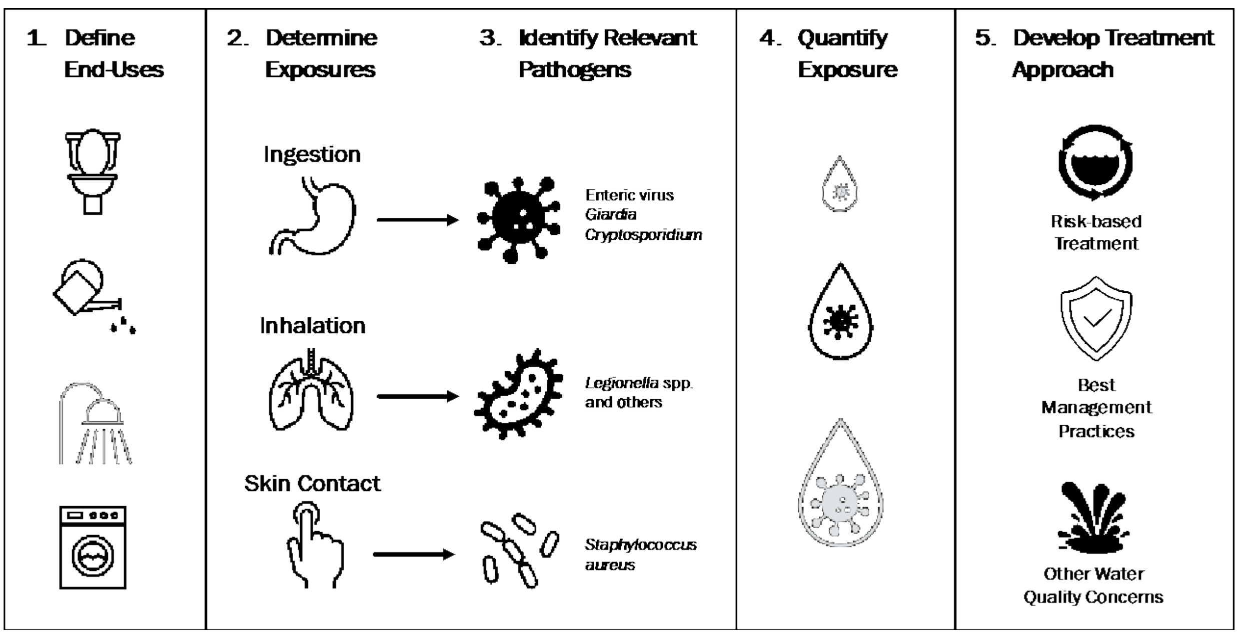


Figure 4.1 Framework for Evaluating Pathogen Exposure Pathways and Treatment Approaches for Single-Family Graywater Systems

4.1 IAP Position Statements

The IAP compiled position statements on the risks of enteric and opportunistic pathogens, best management practices, and policy recommendations for proper O&M of single-family graywater systems.

4.1.1 Are Pathogenic Enteric Viruses, Bacteria, and Protozoa a Concern for Single-Family Graywater Systems?

IAP Position Statement:

Existing risk models suggest that enteric pathogens are a concern for single-family graywater reuse systems.

4.1.2 What Guidance Can Be Applied to Reliably Minimize/Reduce Risks from Pathogenic Enteric Viruses, Bacteria, and Protozoa?

IAP Position Statement:

- Risk-based log reduction targets are an applicable approach for pathogenic enteric viruses, bacteria, and protozoa. The prevalence of other disease transmission pathways within a home may be used to justify an appropriate risk benchmark for these systems (*e.g.*, 10^{-2} rather than 10^{-4} infections pppy).
- Treatment in single-family graywater reuse systems is driven by virus removal.
  - Only viruses have a non-zero 95^{th} percentile LRT for a 10^{-2} infections pppy benchmark, based on results from the Eawag publication (Reynaert et al. 2024).
  - Single-family graywater reuse systems need to achieve a 5.0 log reduction target for virus to achieve risk benchmark of 10^{-2} infection pppy (Reynaert et al. 2024). Although irrigation was not the IAP's emphasis, previous work has shown that LRTs for unrestricted irrigation are less than or equal to those for indoor use (Sharvelle et al. 2017). Therefore, the 5.0 LRT for virus could also be conservatively applied to irrigation.
  - NSF/ANSI 350-2023 includes valuable requirements for materials, design and construction, performance, and minimum service obligations for single-family reuse systems, yet is not explicitly risk based and optional LRTs are not provided for this setting (although those specified for multi-family and commercial systems would be protective). Previous work indicates that certified systems may not achieve adequate virus removal to meet risk-based targets (Schoen et al. 2020).

4.1.3 Are Opportunistic Pathogens a Concern for Single-Family Graywater Reuse Systems?

IAP Position Statement:

- Sufficient information exists to indicate an enhanced risk of opportunistic pathogen growth, such as *Legionella* spp., in single-family graywater reuse systems compared to potable water.

  - Factors contributing to this enhanced risk include variable treatment levels, storage at elevated temperatures, variable water ages, higher nutrient contents, and low or no disinfectant residual (Hamilton et al. 2018, Sharvelle et al. 2017).

4.1.4 What Treatment Technologies and Best Management Practices Can Be Applied to Reliably Control Growth of Opportunistic Pathogens in Single-Family Graywater Reuse Systems?

IAP Position Statement:

- There should be controls in place to reduce the risk of opportunistic pathogens.
  - Table 4.1 outlines the recommended BMPs from the 2017 Risk Based Framework (Sharvelle et al. 2017) and their applicability to single-family graywater systems. All of the recommended BMPs are possible for graywater systems at the single-family dwelling scale.
  - Additionally, users should follow all manufacturer recommendations for proper operation and maintenance.

Table 4.1 Applicability of BMPs from Sharvelle et al. (2017) for Single-Family Graywater Systems

Approach	Description	Applicability	Example/Justification
Flushing the premise plumbing	The required frequency of premise plumbing flushing varies depending upon the quality of water transmitted, detention time in the premise plumbing, temperature of the water, and nature of the premise plumbing components. Periodic flushing is a good means of both removing sediments and scouring pipe walls. Premise plumbing design must include means for easily flushing pipes as part of routine maintenance.	Routine flushes of the premise plumbing are achievable within single-family home graywater systems and should be performed after extended periods of disuse.	Flushing and periodic discharge of stored water could be implemented by means of simple solenoid valves and included in system O&M procedures.
Producing highly disinfected non-potable water	Low concentrations of microbes resulting from filtration and advanced disinfection have a reduced potential for regrowth if organic carbon levels are low. Otherwise, there may be a need for a residual disinfectant to manage growth in larger community systems that produce aerosols. Post-treatment disinfection with ultraviolet (UV) radiation is a recommended means of disinfection that does not increase levels of assimilable organic carbon or biodegradable dissolved organic carbon.	Disinfection mechanisms such as UV reactors and pasteurization are practical to implement, in addition to a chlorine residual.	Small and effective UV reactors are available. A system with storage could use online monitoring or local sensors to monitor system performance.
Maintaining a residual disinfectant	Different disinfectants offer advantages and disadvantages to overall water quality and system management. In general, a higher disinfectant residual provides lower regrowth. Many design and operation considerations are available for each specific system. The Panel [2017] recommends that a free chlorine residual of 0.2 mg/L (Cervero-Arago et al. 2014) or monochloramine residual of 2 to 3 mg/L (Marchesi et al. 2013) be maintained at or near the point of use to control microbial growth. Using disinfectant booster stations within the distribution system is one way to ensure adequate disinfectant residual for systems with long detention times. Chloramine provides a better residual duration as compared to chlorine. Various combinations of UV, chlorine, chloramine, ozone, and hydrogen peroxide are beneficial for specific disinfection goals. Periodic shock treatments with disinfectants and continuous disinfection looping of reservoirs help reduce the potential for regrowth and manage issues with biofilms (LeChevallier, 2003). Stagnation resulting from dead zones or prolonged periods of zero-flow or low flow that create long residence times and allow disinfectants to dissipate and sediments to deposit result in improved conditions for regrowth and should be avoided.	Disinfectant residuals are practical to maintain in a single-family home graywater system and may be used as a control against opportunistic pathogens and biofilm growth.	NSF/ANSI 350-2023 requires a chlorine residual of 0.5 – 2.0 mg/L for residential graywater systems (see Section 2.3.1).
Using non-reactive, biologically stable materials of construction	Avoid the use of corrosive materials or organic materials that tend to protect microorganisms from disinfection and enhance the regrowth environment by the adsorption of organic compounds (LeChevallier et al. 1990).	Non-reactive, biologically stable materials of construction can be incorporated into system design.	N/A
Producing non-potable water low in carbonaceous material and nutrient content	The primary energy source for pathogen regrowth is organic carbon measured as assimilable organic carbon, biodegradable dissolved organic carbon, total organic carbon, and other essential nutrients, including nitrogen (N), phosphorous (P), and iron (Fe); therefore, the primary means to reduce the regrowth potential of pathogens is to provide highly treated water.	Controls against *Legionella* spp. and biofilm growth are recommended. However, it is anticipated that water quality from smaller systems that are not properly maintained and operated may experience upsets or not have sufficient biological activity to reliably achieve nutrient and organics removal. Focus should be applied to verification of a disinfectant residual.	N/A
Controlling temperature	Avoid the storage and distribution of non-potable water within 20 to 45°C (Health and Safety Executive, 2013d) to reduce the potential for pathogen regrowth. Otherwise, consider a disinfection residual or point-of-use systems, particularly if aerosols are generated. Heat recovery from warm waters, particularly graywater and wastewater, can offer the benefit of reducing the temperature at which these waters are stored. Additionally, hot-water heater temperature should be maintained above 60°C (National Academies of Sciences, Engineering, and Medicine, 2020).	Temperature control is possible within storage and premise plumbing. However, cooling or heating the outlets prior to dwelling entry may significantly increase energy consumption and reduce system economic feasibility.	N/A
Cleaning storage tanks	The required frequency of storage tank cleaning varies depending on the quantity of water stored, detention time in storage, temperature of the water, and nature of the tank. Tanks that are open to the atmosphere require more frequent cleaning.	Storage tanks should be regularly cleaned, and stored water detention time should be minimized. Manufacturers should provide instructions to the user on the maintenance protocol for storage tanks after extended periods of disuse.	O&M as well as training should include this best practice.

Notes: Adapted from the 2017 Risk Based Framework (Sharvelle et al.2017).

4.1.5 What Policy, Guidance, or Incentive Programs Can Be Used to Result in the Proper Operation and Maintenance of Single-Family Graywater Reuse Systems?

IAP Position Statement:

- Rebates provided for single-family graywater systems should include the following conditions:
  - Training on potential risks, proper use, and maintenance is provided.
  - A subscription to a maintenance package is made available (rebates could also cover annual maintenance packages).
  - Manufacturer warranties can be linked to maintenance requirements.
  - It is recommended to use continuous monitoring systems or local sensors to monitor system performance. The graywater reuse system must be disclosed upon sale of the dwelling and information related to rebate conditions provided (*e.g.*, the new dwelling owner or renter should be given access to training and maintenance subscription packages).
  - User feedback should be collected on items such as customer experience, ease of use, reliability, frequency of maintenance, frequency the reuse mode was utilized, and estimated water savings.

4.2 IAP Suggested Amendments to the Current Industry Guidance for Single-Family Graywater Systems

Both NSF/ANSI 350-2023 and IAPMO/ANSI Z1324-2022 standards establish minimum requirements for onsite commercial and multi-family residential water reuse systems. The IAP is recommending the following actions:

- Amend NSF/ANSI 350-2023 standard to include the recommended LRTs for single-family residential settings and other recommendations from the IAP.
- Amend IAPMO/ANSI Z1324-2022 standard to include the recommended LRTs applicable to the single-family scale and other recommendations from the IAP.

4.3 Summary of Single-Family Water Graywater Systems

- The IAP concluded a 5.0 log reduction target for virus is needed for single-family graywater reuse systems to achieve the risk benchmark of 10^{-2} infections pppy.
- Third party certifications are valuable, yet they do not currently guarantee that risk targets are met.

- The IAP is recommending that the SFPUC endorse the use of single-family graywater systems which comply with amended NSF/ANSI 350-2023 and/or IAPMO/ANSI Z1324-2022 standards that include recommended LRTs for the single-family scale and other IAP recommendations.
- The IAP concluded user exposure to opportunistic pathogen growth in a single-family graywater reuse system is a concern. Table 4.1 outlines the recommended BMPs to control for opportunistic pathogen growth.
- The IAP recommended use of continuous monitoring systems or local sensors to monitor system performance. Reuse water should be automatically diverted during out of specification conditions or when maintenance activities are not performed.
- To promote appropriate maintenance practices, rebates and warrantees can be linked to user training, service packages and/or regular maintenance requirements.
- While common treatment systems previously considered for graywater water reuse (*e.g.*, MBR with UV and/or chlorine disinfection) may be sufficient to meet a virus LRT of 5.0, additional research is needed to identify more energy efficient treatment trains. The IAP is recommending that the SFPUC endorse energy efficient single-family graywater systems.
- For the SFPUC to encourage single-family graywater reuse system implementation, a policy should be adopted that the graywater reuse system be disclosed upon sale of the home and information related to applicable rebate conditions provided (*e.g.*, the new homeowner should be given access to training and maintenance subscription packages).

5 RECIRCULATING CLOTHES WASHERS

Recirculating clothes washers allow users to reuse water from the rinse portions of the laundry cycle in the wash portion of the next load(s). Rinse water is stored and treated between laundry cycles. Recirculating clothes washers are similar to single-family graywater systems because they store, treat, and reuse graywater onsite, the key difference being that the source water and end use is restricted to clothes washing.

The IAP assumed the following operating principles for recirculating clothes washers:

- Users can select potable (conventional mode) or recirculated rinse water.
- Only the rinse portions of the laundry cycle are recirculated in the wash portion of subsequent loads.
- Rinse water is stored and treated between uses.

The IAP referred to the framework developed by Trussell Technologies (2023) for pathogen exposure pathways and treatment approaches for recirculating clothes washers. As shown in Figure 5.1, the framework outlines the relevant exposure routes, pathogen risks, and treatment approaches for recirculating clothes washers.

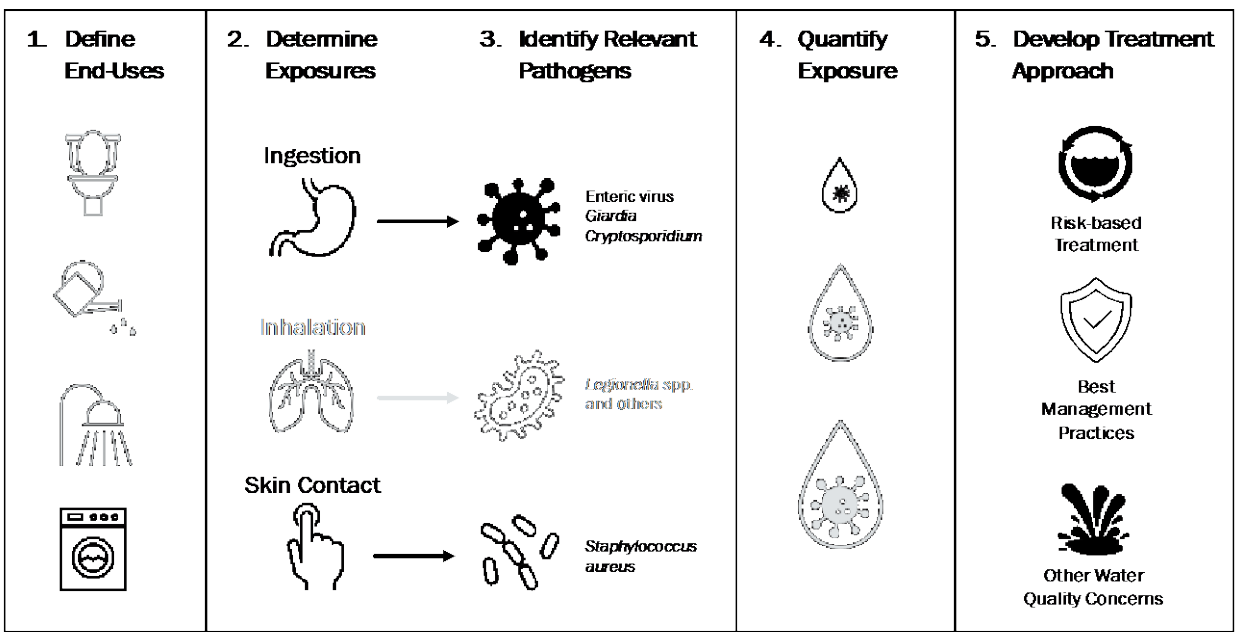


Figure 5.1 Framework for Evaluating Pathogen Exposure Pathways and Treatment Approaches for Recirculating Clothes Washers

5.1 IAP Position Statements

The IAP compiled position statements on the risks of enteric and opportunistic pathogens, risk reduction strategies, best management practices, and policy recommendations for proper O&M of recirculating clothes washers. The IAP also provided a position statement regarding recirculating clothes washers that do not store water between laundry cycles.

5.1.1 Are Pathogenic Enteric Viruses, Bacteria, and Protozoa a Concern for Recirculating Clothes Washers that Store Water Between Clothes Washing Uses?

IAP Position Statement:

Enteric pathogens in recirculating clothes washers with storage are a concern because pathogens from one laundry load could contaminate the water used in the next and may expose different users. However, like single-family graywater systems, other transmission pathways within the home are likely to dominate exposure risks.

5.1.2 What Guidance Can Be Applied to Reliably Minimize/Reduce Risks from Pathogenic Enteric Viruses, Bacteria, and Protozoa?

IAP Position Statement:

- Based on risk models, treatment of enteric pathogens in recirculating clothes washers is driven by virus removal. Biofilm colonization in between uses is an additional, yet lower concern.
- Similar treatment guidance for single-family graywater reuse systems can be applied to recirculating clothes washers with storage, given operational similarities such as the storage of water and risk of exposure between multiple users.
- The IAP concluded a 3.0 log reduction target for virus is needed for recirculating clothes washers to achieve the risk benchmark of 10^{-2} infection pppy.

5.1.3 Are Opportunistic Pathogens a Concern for Clothes Washers?

IAP Position Statement:

Sufficient information exists to indicate an enhanced risk of opportunistic pathogen growth, such as *Legionella* spp., when storing water for recirculating clothes washers. However, *Legionella* spp. and other pathogens that can be transmitted through inhalation pose less of a risk in the case of clothes washers (*e.g.*, relative to showers) due to fewer opportunities for users to be exposed to aerosols. Biofilm colonization could be possible in between uses.

5.1.4 What Treatment Technologies and Best Management Practices (BMPs) Can Be Applied to Reliably Control Growth of Opportunistic Pathogens in Recirculating Clothes Washers?

IAP Position Statement:

- Treatment processes that are properly monitored to meet applicable enteric pathogen log-reduction targets can provide robust and reliable treatment.
  - The BMPs outlined in Table 4.1 are applicable to recirculating clothes washers. All of the recommended BMPs are possible for recirculating clothes washers.

5.1.5 What Policy, Guidance, or Incentive Programs Can Be Used to Result in the Proper Operation and Maintenance of Recirculating Clothes Washers?

IAP Position Statement:

- Rebates can be given for recirculating clothes washers with the following conditions:
  - Training on potential risks, proper use and maintenance is provided,
  - A subscription to a maintenance package related to treatment systems is provided (rebates could also cover annual maintenance packages).
  - Manufacturer warranties can be linked to maintenance requirements.
  - It is recommended to use continuous monitoring systems or local sensors to monitor system performance. Water should be diverted when out of specification conditions occur.
  - The recirculating clothes washers must be disclosed upon sale of the dwelling and information related to rebate conditions provided (*e.g.*, the new dwelling owner or renter should be given access to training and maintenance subscription packages).
  - User feedback should be collected on items such as ease of use, reliability, frequency of maintenance, frequency the reuse mode was utilized, and estimated water savings.

5.1.6 Does this Guidance Apply to Recirculating Clothes Washers Without Storage?

IAP Position Statement:

- While these systems are not known to exist, it is anticipated that they would recirculate water during the laundry cycle and not store for reuse in the next load.
- In this event, hazard characterization and exposure risks are largely comparable to conventional washing machines.
- Specific risk-based treatment is not proposed, but potential for opportunistic pathogen growth and cross-connection should be considered.

5.2 IAP Suggested Amendments to Current Industry Guidance for Recirculating Clothes Washers

Similar to the other single-family water reuse applications evaluated in this report, the IAP looked for existing industry guidance and standards applicable to recirculating clothes washers. The IAP found that currently there are no existing standards for recirculating clothes washers. If the marketplace for recirculating clothes washers further develops, the IAP recommends that a certification standard be developed for this application in accordance with the IAP recommendations.

5.3 Summary of Recirculating Clothes Washers

- Recirculating clothes washers are similar to single-family graywater systems in that they collect, treat, and store water for later use. Therefore, the same recommendations for enteric and opportunistic pathogen control apply. Using the risk benchmark of 10^{-2} infections pppy, the virus LRT is 3.0.
- The BMPs outlined in Table 4.1 for opportunistic pathogen control are applicable to recirculating clothes washers.
- Currently there are no existing standards for recirculating clothes washers. If the marketplace for recirculating clothes washers further develops, the IAP recommends that a certification standard be developed for this application in accordance with the IAP recommendations.
- It is recommended to use continuous monitoring systems or local sensors to monitor system performance. Reuse water should be automatically drained instead of recirculated during out of specification conditions or when maintenance activities are not performed.
- Fail-safe backflow prevention is important for recirculating clothes washers.
- Recirculating clothes washers without storage, *i.e.*, reusing water within the same load, are considered comparable in exposure risks to conventional (non-recirculating) washers and were not included in the analysis.

- To promote appropriate maintenance practices, rebates and warrantees can be linked to user training, service packages and/or regular upkeep requirements.

The IAP recommends that if the SFPUC determines to encourage the implementation of energy efficient recirculating clothes washers, a policy should be adopted that the recirculating clothes washer be disclosed to the new homeowner or renter upon sale of the home and information related to applicable rebate conditions provided (*e.g.*, the new homeowner should be given access to training and maintenance subscription packages).

6 RECIRCULATING SHOWERS

Recirculating showers recycle water in a during a single shower event. Water is collected from the floor drain or water collection tank, treated, and released from the showerhead. Recirculating showers differ from single-family graywater systems and recirculating clothes washers in that water is not stored between uses of the shower. High aerosolization rates and enhanced face immersion also differentiate recirculating showers from bathtubs and hot tubs where users are likewise exposed to their own bathing water.

The IAP was not tasked with evaluating specific products available in the market; however, three recirculating shower manufacturers provided an overview of system operating principles for informational purposes only (Table 6.1). This report does not validate or refute manufacturer claims on recirculating showers which are available in the marketplace and/or proposed for the marketplace. The recommendations by the IAP are not specific to commercially available products, but rather generally describe features of recirculating showers deemed to be important to be protective of public health.

The IAP assumed the following operating principles for recirculating showers:

- Water is recirculated within a single shower use and discharged to the drain following the conclusion of the shower.
- Users can choose to select potable (conventional) or recirculation mode.
- Recirculates water from the floor drain or water collection tank to the showerhead when recirculation mode is selected; water is treated between collection and release from the showerhead.
- Reuse water is not retained or stored between showers and thus used shower water is not shared between multiple users.
- There is a cleaning cycle between users (*e.g.*, with heat or chemical treatment) and each new cycle starts with a new batch of fresh water.
- Outside the U.S. there may be other applicable water quality standards that are not covered in this report.

Table 6.1 Comparison of Select Recirculating Shower Technologies

Vendor	Recirculation Intake	Heat Source	Inline Treatment	Routine Cleaning / Disinfection Between Uses	Maintenance Tasks
A	Drain reservoir	Municipal hot water	▪ 200-micron filter ▪ >30 mJ/cm^2 UV light @ 3 gpm ▪ 0.5 gpm continuous potable inflow	▪ Potable flush ▪ Chlorine solution circulation and retention	▪ Monthly deep clean/biofilm removal ▪ Periodic anti-scalant circulation ▪ Cleaning solution replacement
B	Drain reservoir	Internal heater	▪ Automatic recirculation filtration based on real-time monitoring of turbidity & electrical conductivity ▪ Mechanical filtration (range): 0.1micron – 100 micron ▪ >40 mJ/cm^2 UV light @ 3 gpm	▪ 180°F pasteurization ▪ Potable flush	▪ Every third day pasteurization cycle, discharged through shower head ▪ Periodic anti-scalant circulation
C	Shower floor suction	Municipal hot water	▪ Prefilter (200 micron) ▪ Main filter (100 micron) ▪ UV light (approximately 45 mJ/cm^2 @ 3 gpm; specification is 300 J/m^2 @ 19 L/min)	▪ System drain ▪ Potable backflush	▪ Biweekly chlorine tablet rinse cycle ▪ Monthly filter replacement

mJ/cm^2 – millijoules per square centimeter; J/m^2 – joules per square meter; L/min – liters per minute.

The IAP referred to the framework developed by Trussell Technologies (2023) for pathogen exposure pathways and treatment approaches for recirculating showers. As shown in Figure 6.1, the framework outlines the relevant exposure routes, pathogen risks, and treatment approaches for recirculating showers.

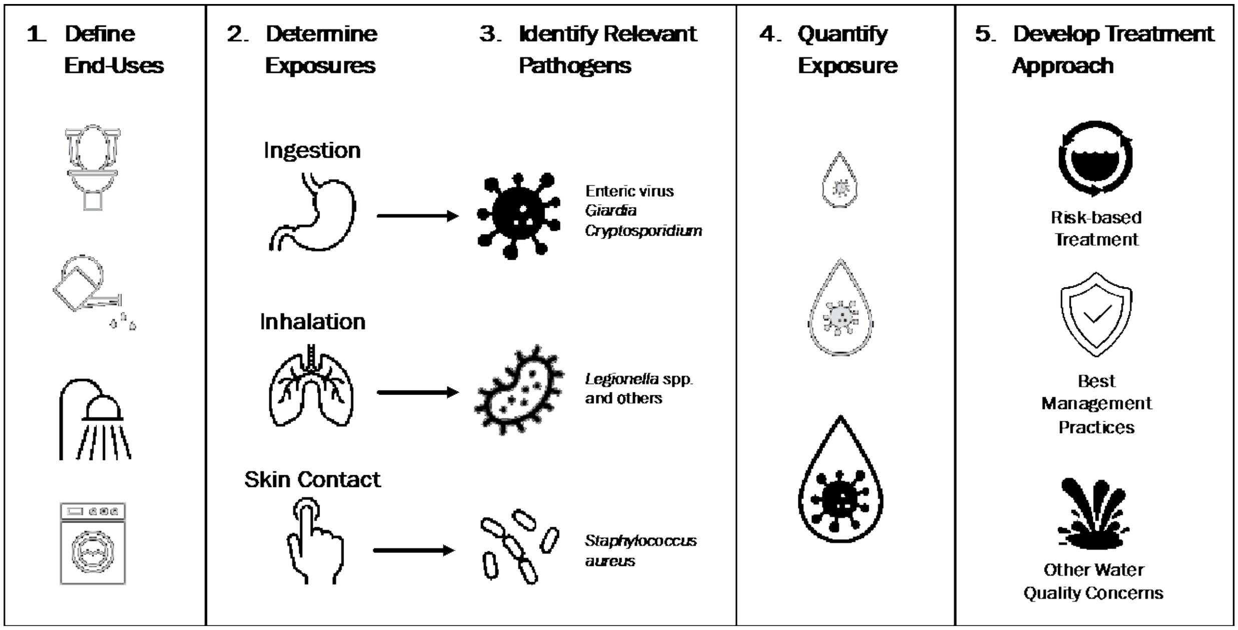


Figure 6.1 Framework for Evaluating Pathogen Exposure Pathways and Treatment Approaches for Recirculating Showers

6.1 Advisory IAP Position Statements

The IAP provided position statements on the risks of enteric and opportunistic pathogens, best management practices, and policy recommendations for proper O&M of recirculating showers. The IAP provided additional information on pathogen concerns, special considerations, treatment technologies and BMPs, as well as current industry guidance for these systems.

6.1.1 Are Pathogenic Enteric Viruses, Bacteria, and Protozoa a Concern where the Water is Only Recirculated for One User in a Single-Family Household?

IAP Position Statement:

- Aerosolization, ingestion, and dermal exposures are likely occur at high rates in showers. Additional illnesses via reinfection or autoinfection of other body tissues/organs within a single user could be possible. However, such risks have not yet been quantitatively assessed due to insufficient information when considering that that user is also the source of the pathogens (*i.e.*, from feces removed during bathing). Biofilm colonization could also present the potential to expose other users.

- When considering comparative risk, the risk of person-to-person enteric pathogen transmission via recirculating shower water is likely much smaller than other routes in a household, given that most users shower separately and are not directly exposed to other users' water. Therefore, enteric pathogen management is not the emphasis for protecting public health during the use of recirculating showers. However, although quantitative pathogen reduction targets could not be specified given the uncertainties above, precautionary treatment and disinfection is advisable.

6.1.2 What Guidance can be Applied to Reliably Minimize/Reduce Risks from Pathogenic Enteric Viruses, Bacteria, and Protozoa?

IAP Position Statement:

- While enteric pathogen management is not the emphasis for recirculating showers, the IAP recommends disinfection be used to treat the recirculated water, given the uncertainties mentioned above:
  - At a minimum, the IAP is recommending the use of NSF/ANSI 55 Class A validated UV reactors, which are designed to be used for treating water of unknown quality. Recirculating showers should also include adequate pretreatment prior to the UV. The IAP is recommending that filtration standards appropriate for treatment of non-potable water be identified and/or specific water quality limits (*e.g.*, BOD, TSS, HPC, turbidity) be defined. Online monitoring or local sensors should be used to ensure that the water entering the UV meets reactor specifications.

6.1.3 Are Opportunistic Pathogens a Concern for the Shower User where the Water is Only Recirculated for One User?

IAP Position Statement:

- The IAP determined that the primary concern for recirculating showers is an enhanced risk of opportunistic pathogen growth, such as *Legionella* spp., compared to conventional showers because organic matter and non-microbial contaminants such as soap and shampoo are present in the recirculated water which could lead to biofilm and opportunistic pathogen growth in the drain, piping, showerhead, and other system components when the water is recirculated. Furthermore, aerosol generation via showers is a known exposure pathway for legionellosis cases as well as other diseases from other opportunistic pathogens such as nontuberculous mycobacteria.

- Additional concerns exist for infections caused by skin-associated bacteria such as *Staphylococcus aureus* and *Pseudomonas aeruginosa*, which can cause delayed health effects in a colonized individual.
- The IAP recommends that individuals using recirculating showers consult one's doctor if they have skin issues, open wounds, and/or are immunocompromised, as these and related conditions may increase potential risks.

6.1.4 What Treatment Technologies and Best Management Practices (BMPs) Can Be Applied to Reliably Control Growth of Opportunistic Pathogens Within the Shower Recirculation System?

IAP Position Statement:

- A summary of applicable best practices for microbial growth control in recirculating showers based on recommendations from the 2017 Risk Based Framework (Sharvelle et al. 2017) is presented in Table 6.2.
- The reduction of dissolved organics is necessary to ensure effectiveness of disinfection and reduce risk of colonization of opportunistic pathogens in the system. Dissolved organics removal, typically achieved through biological treatment, sorption media, and/or membrane filtration, is needed to achieve water with an appropriate turbidity for effective UV disinfection.
- A routine cleaning cycle between users is recommended to minimize biofilm growth and potential pathogen carryover. Additional deep-cleaning cycles, as used by several current technologies (Table 6.1), are also recommended to periodically remove any sediments or biofilms from the system.
- Chemical-based disinfection between shower uses can be an effective means to reduce biofilm growth and the cross-contamination of pathogens between users. Chemical safety concerns should be considered in system design, including barriers to ensure that users are not exposed to chemically treated water used in cleaning cycles.
- Pasteurization can provide reliable disinfection during a cleaning cycle when combined with performance monitoring. During pasteurization, it should be demonstrated that all components of the system, including the showerhead and drain, are treated to the specified temperature (*e.g.*, 160 degrees F for 10 seconds)

and that measures are in place to prevent the user from coming into contact with the hot pasteurization solution to avoid scalding.

- Additional BMPs are recommended:
  - Automated diversion during periods of high organic loads (*e.g.*, while washing with soaps and shampoos). Sensors may be utilized to automatically switch the shower into conventional mode when specific water quality parameters (*e.g.*, high conductivity or turbidity) are detected.
  - No prolonged storage or stagnation of water in the system.
  - Automated diversion if maintenance activities are not conducted.
  - Routine cleaning of shower surfaces.
  - Automated cleaning cycles in long periods without usage.

Table 6.2 Applicability of Best Practices for Microbial Growth Control from Sharvelle et al. (2017) for Recirculating Showers

Approach	Description	Applicability	Example/Justification
Flushing the premise plumbing	The required frequency of premise plumbing flushing varies depending upon the quality of water transmitted, detention time in the premise plumbing, temperature of the water, and nature of the premise plumbing components. Periodic flushing is a good means of both removing sediments and scouring pipe walls. Premise plumbing design must include means for easily flushing pipes as part of routine maintenance.	While flushing can be beneficial, disinfection (including but not limited to chemical-based disinfection or pasteurization) during cleaning cycles in between shower uses is further recommended.	Vendor A recirculating shower system conducts a potable water flush and chlorine solution circulation after every use. Vendor B shower system pasteurizes the water in the system and then circulates and flushes this water after each use. Vendor C shower system empties all water and conducts a backflush after each use.
Producing highly disinfected non-potable water	Low concentrations of microbes resulting from filtration and advanced means of disinfection have a reduced potential for regrowth if organic carbon levels are low. Otherwise, there may be a need for a residual disinfectant to manage growth in larger community systems that produce aerosols. Post-treatment disinfection with ultraviolet (UV) radiation is a recommended means of disinfection that does not increase levels of assimilable organic carbon or biodegradable dissolved organic carbon.	Disinfection of the recirculated water should occur using a NSF/ANSI 55 Class A validated UV reactor, which are designed to be used for treating water of unknown quality. To ensure adequate pretreatment prior to the UV, a filtration standard appropriate for treating non-potable water should be identified and referenced and/or specific water quality limits (*e.g.*, BOD, TSS, HPC, turbidity) should be defined. Online monitoring or local sensors can be used to ensure that the water entering the UV meets reactor specifications.	Vendor A shower system uses UV at a 30 mJ/cm^2 dose. Vendor B shower system uses UV at a minimum dose of 40 mJ/cm^2. Vendor C shower system uses UV at a dose of approximately 45 mJ/cm^2. IAPMO IGC 330-2023 specifies a UV dose of 30 mJ/cm^2. However, existing technologies and standards do not adequately address pretreatment for effective UV; IAPMO IGC 330-2023 specifies only a cartridge filter.
Maintaining a residual disinfectant	Different disinfectants offer advantages and disadvantages to overall water quality and system management. In general, a higher disinfectant residual provides lower regrowth. Many design and operation considerations are available for each specific system. The Panel recommends that a minimum free chlorine residual of 0.2 mg/L (Cervero-Arago et al. 2014) or monochloramine residual of 2 to 3 mg/L (Marchesi et al. 2013) be maintained at or near the point of use to control microbial growth. Using disinfectant booster stations within the distribution system is one way to ensure adequate disinfectant residual for systems with long detention times. Chloramine provides a better residual duration as compared to chlorine. Various combinations of UV, chlorine, chloramine, ozone, and hydrogen peroxide are beneficial for specific disinfection goals. Periodic shock treatments with disinfectants and continuous disinfection looping of reservoirs help reduce the potential for regrowth and manage issues with biofilms (LeChevallier, 2003). Stagnation resulting from dead zones or prolonged periods of zero-flow or low flow that create long residence times and allow disinfectants to dissipate and sediments to deposit result in improved conditions for regrowth and should be avoided.	Maintaining a chemical residual in a recirculating shower system is impractical. However, periodic shock treatments with disinfectants may be conducted to control biofilm growth, particularly after periods of zero-flow or low flow.	Vendor A shower system injects a chlorine-based cleaner between every use for a 45 second cleaning cycle and injects a separate cleaning solution intended to target biofilm once a month for a 10-minute cleaning cycle. Vendor B shower system has a manually activated cleaning mode in which a sodium hydroxide tablet or descaling tablet is dropped on the shower floor for the system to recirculate over a period of 5 minutes before evacuating and flushing the system. Vendor C shower system employs a system rinse at a minimum frequency of every 2 weeks in which a chlorine tablet is dropped on the shower floor, circulated and then flushed out using potable water.
Using non-reactive, biologically stable materials of construction	Avoid the use of corrosive materials or organic materials that tend to protect microorganisms from disinfection and enhance the regrowth environment by the adsorption of organic compounds (LeChevallier et al. 1990).	Non-reactive, biologically stable materials of construction can be incorporated into system design.	IAPMO IGC 330-2023 details a number of construction material and related building standard requirements

Approach	Description	Applicability	Example/Justification
Producing non-potable water low in carbonaceous material and nutrient content	The primary energy source for pathogen regrowth is organic carbon measured as assimilable organic carbon, biodegradable dissolved organic carbon, total organic carbon, and other essential nutrients, including nitrogen (N), phosphorous (P), and iron (Fe); therefore, the primary means to reduce the regrowth potential of pathogens is to provide highly treated water.	The reduction of dissolved organics is necessary to ensure effectiveness of disinfection and reduce risk of colonization of opportunistic pathogens in the system. Dissolved organics removal, typically achieved through biological treatment, sorption media, and/or membrane filtration, is needed to achieve water with an appropriate turbidity for effective UV disinfection.	Existing technologies and Standards do not explicitly address removal of organic matter.
Controlling temperature	Avoid the storage and distribution of non-potable water within 20 to 45°C (Health and Safety Executive, 2013d) to reduce the potential for pathogen regrowth. Otherwise, consider a disinfection residual or point-of-use systems, particularly if aerosols are generated. Heat recovery from warm waters, particularly graywater and wastewater, can offer the benefit of reducing the temperature at which these waters are stored.	Maintain hot water temperature at a set point of 60°C to avoid growth of *Legionella* spp. in premise plumbing.	N/A
Cleaning storage tanks	The required frequency of storage tank cleaning varies depending on the quantity of water stored, detention time in storage, temperature of the water, and nature of the tank. Tanks that are open to the atmosphere require more frequent cleaning. Additionally, hot-water heater temperature should be maintained above 60°C (National Academies of Sciences, Engineering, and Medicine, 2020).	Recirculating showers should not store water between uses. Users should perform normal shower cleaning.	N/A

Adopted from the 2017 Risk Based Framework (Sharvelle et al. 2017)

6.1.5 What Policy, Guidance, or Incentive Programs Can Be Used to Result in the Proper Operation and Maintenance of Recirculating Showers?

IAP Position Statement:

- The IAP recommends that the SFPUC endorse the use of recirculating showers which comply with an amended IAPMO 330-2023 that is consistent with recommendations by the IAP. The IAP recommends that IAPMO IGC 330-23 adopt modifications as described in Section 6.2 below.
- To ensure the proper operation and maintenance of recirculating showers, the IAP recommends the following conditions:
  - Training for the user on potential risks, proper use, and maintenance
  - A subscription to a maintenance/service package.
  - Manufacturer warranties be linked to maintenance requirements.
  - Continuous monitoring systems or local sensors to monitor system performance. Automated diversion of the water when out of specification water quality conditions occur.
  - Recirculating showers to be disclosed upon sale of the dwelling and information provided on user training and maintenance subscription packages.
  - If a rebate program is implemented, collection of user feedback on items such as ease of use, reliability, frequency of maintenance, frequency the reuse mode was utilized, and water savings.
  - Proper labeling of the recirculating showers that identify potential risks.

6.2 IAP Suggested Amendments to the Current Industry Guidance for Recirculating Showers

The IAPMO IGC 330-2023 for recirculating showers details a number of construction material and related building standard requirements and also a requirement for filtration and disinfection (IAPMO, 2023). The IAP recommends the following adjustments to the IAPMO IGC 330-2023:

- References to NSF/ANSI 42, NSF/ANSI 53, and NSF/ANSI 55 Class B systems should be removed as these standards are only applicable to microbiologically safe drinking water. To ensure adequate pretreatment prior to the UV, filtration standards appropriate for treating non-potable water should be identified and referenced and/or specific water quality limits (*e.g.*, BOD, TSS, HPC, turbidity) should be defined. Online monitoring or local sensors can be used to ensure that the water entering the UV reactors meets reactor specifications.

- Require the use of only NSF/ANSI 55 Class A validated UV reactors, which are designed to be used for treating water of unknown quality. References to NSF/ANSI 55 Class B validated UV reactors should be removed as they are only applicable to supplemental treatment of microbiologically safe drinking water.
- Existing testing requirements are insufficient for demonstrating microbial risk management. Develop a test protocol for incorporation into IAPMO IGC 330-2023 to ensure the treatment and routine cleaning cycle is operating effectively. Test protocol should include but not be limited to characteristics of the challenge water, volumes, testing schedule, and analytical methods.
- Add the following design requirements:
  - » Recirculating shower system shall be designed with the ability to switch to conventional mode and fully drain when sensors indicate the water quality of the recirculated water is off specification. Monitoring sensors could be tied to the UV operating envelope.
  - » Recirculating shower systems shall be designed such that all wetted shower components shall be disinfected, including but not limited to chemical-based disinfection or pasteurization, during cleaning cycles in between every shower use. Contact times, disinfectant doses, and temperatures should be specified.
  - » Recirculating shower systems shall be designed such that the recirculating shower system shall be fully drained after every shower use.
  - » Plumbing components shall be constructed of non-reactive, biologically stable materials.
  - » Recirculating shower systems shall include labeling that identify potential risks.
- Specify a requirement for a user manual that includes the following:
  - » Basic operation and maintenance requirements.
  - » Inclusion of a disclaimer that immunocompromised individuals or those with respiratory diseases are at a higher risk of negative health outcomes and should consult their physician prior to use.
  - » Instructions on the safe use of the recirculating shower system after extended periods of disuse.

6.3 Summary of Recirculating Showers

The IAP recommends the following for recirculating showers:

- The primary concern for recirculating showers is an enhanced risk of opportunistic pathogen growth, such as *Legionella* spp., compared to conventional showers.

- Risks of infections caused by skin-associated bacteria, enteric pathogens, and autoinfection were not quantitatively assessed, but are also of concern. UV disinfection can address these concerns using a validated reactor (NSF/ANSI 55 Class A) with adequate pretreatment prior to the UV. Online monitoring or local sensors can be used to ensure that the water entering the UV reactors meets reactor specifications.
- The reduction of dissolved organics is necessary to ensure the safe operation of the recirculating shower system and the effectiveness of disinfection.
- Implementation of organics removal, cleaning cycles, and best management practices are recommended to reliably control growth of opportunistic pathogens.
- Immunocompromised individuals or those with respiratory diseases are at a higher risk of negative health outcomes from opportunistic pathogens. The IAP recommends that individuals using recirculating showers consult one's doctor if they have skin issues, open wounds, and/or are immunocompromised.
- The IAP identified the need for specific modifications to IAPMO IGC 330-23 to incorporate the IAP's treatment recommendations and address gaps related to testing procedures and user awareness. An associated certification process should be developed to demonstrate that systems meet these criteria.
- The IAP recommends that the SFPUC endorse the use of recirculating showers which comply with an amended IAPMO 330-2023 that is consistent with recommendations by the IAP.

7 MONITORING FOR SINGLE-FAMILY WATER REUSE APPLICATIONS

Monitoring and maintenance of single-family dwelling water reuse systems is essential for their ongoing safe use. The IAP acknowledges that installation of online monitoring for individual treatment technologies used in a single-family dwelling may not be available and/or could increase cost and present practical barriers to the implementation of reuse; these become further challenging when moving to appliance scale. However, continuous monitoring is a cornerstone of the risk-based approach and essential to ensuring that public health goals are met during ongoing operation of the systems. Industry standards should be amended such that single-family water reuse systems are certified to include the IAP's recommendations, such as LRTs for some systems. Certified single-family water reuse systems could then use continuous monitoring systems or local sensors to monitor system performance. The LRTs and other risk management practices assume that the specified treatment and operational systems function as designed yet are sensitive to real-world process upsets and malfunctions. This is particularly important in onsite systems where there is otherwise limited oversight and a short residence time before users are exposed to treated water. Table 7.1 considers the applicability of monitoring and reporting practices recommended by the 2017 guidance (Sharvelle et al. 2017) to these systems.

Table 7.1 Applicability of Monitoring and Reporting Considerations from Sharvelle et al. (2017) for Single-Family and Appliance Scale Systems

Application	Description	Applicability
Validation	Validate unit processes prior to installation. Validation includes an evaluation study conducted using challenge testing with target pathogens or surrogates over a defined range of operating conditions.	Recommended. Technologies must be validated to demonstrate treatment performance. NSF/ANSI 350 and IAPMO IGC 330 should be amended to reflect the risk-based recommendations of the IAP.
Monitoring	Use continuous monitoring systems or local sensors to monitor system performance.	Recommended. Treatment technologies should be selected for which local sensors or online monitoring solutions exist.
Control and automation	Operate systems (including shut down and start up) based on a specific set of monitoring conditions.	Recommended. Automatic diversion during off-specification conditions is particularly critical in onsite systems where there is a short residence time prior to user exposures.
Alarms	Create automated alarms for appropriate parties using critical malfunction conditions. Characterize these alarms by the degree of response required.	Recommended. Includes both treatment failure and failure to perform maintenance activities.
Field verification	Manually collect water samples for microbial analysis to check system performance in achieving LRTs. The need and scope of field verification depends on the characteristics of the Decentralized Non-Potable Water System, including complexity and risk.	Not required. It is impractical to perform field testing on a large number of small systems. Instead, online monitoring is relied upon to demonstrate validated treatment performance.
Continuous process verification	Provide ongoing confirmation of system performance using sensors to observe selected parameters on a continuous basis, including surrogate parameters correlated with pathogen LRT requirements.	Recommended. Online monitoring is recommended to ensure ongoing treatment performance and rapidly detect any system failures. Treatment technologies should be selected for which local sensors or online monitoring solutions exist.
Data collection	Log and preserve data for a prescribed period and share this data with identified parties. Telemetry systems are used commonly for real-time web-based data monitoring.	Recommended. Data collection on system use, water savings, and treatment performance can be used to evaluate the reuse program and identify whether public health requirements are being met.
Reporting	Provide periodic summary reports to the regulator, preferably in electronic format, and include performance verification by a qualified professional.	Recommended. Requires that an oversight entity is available to review the reports.

To ensure continuous function of water reuse systems, simple periodic maintenance tasks, such as chemical tank checks and filter changes will be necessary, as well as automatic system shutoffs if water quality checks fail or maintenance tasks are not performed. To incentivize these practices, rebates and manufacturer warranties can be linked to monitoring and maintenance requirements. Rebates can be contingent on an initial training of potential risks, proper use, and maintenance, as well as subscriptions to maintenance packages. Upon the sale of a dwelling, water reuse systems and appliances should be disclosed to the new owner and trainings, rebates, and maintenance packages should be made accessible. Labeling that identifies possible risks and a source for operational procedures should be provided on the units.

Longer-term studies of water reuse appliances and graywater systems are needed to verify that biofilm growth will not be a concern, and that opportunistic pathogens can be controlled. Longer-term studies can also provide better information on system performance in real life use conditions, which can be supported by periodic (*e.g.*, annual) reporting to evaluate ongoing success of the water reuse program and the extent to which public health recommendations are practically achieved. More research is also needed to better understand user behavior with regards to frequency of maintenance tasks and user satisfaction. There is potential for partnership between a research institution and SFPUC to carry out long-term performance and behavior analyses.

8 COSTS AND ENVIRONMENTAL IMPACTS

While preventing infections and illnesses associated with exposure to recycled water is the top priority when evaluating household-based graywater systems, broader issues such as life cycle costs and environmental impacts (*e.g.*, energy and water use) should also be considered to understand the overall costs and benefits of widescale adoption.

Table 2.1 summarizes potential water savings for different residential end uses, which estimates up to a 50 percent reduction in water use from recirculating clothes washers and up to an 80 percent reduction in water use from recirculating showers. Such savings also have energy benefits given the reduction of hot water use. These estimates represent the theoretical maximum amount of water savings, and actual water savings may be lower depending on the specific product, operation and maintenance and pathogen controls.

Previous work evaluated the effect of system scale on the life cycle costs and environmental impacts of decentralized reuse, including source separated graywater (Cashman et al. 2018, Arden et al. 2020, 2021). Results indicated a strong inverse relationship between building size (*i.e.*, amount of water recycled) and both cost and environmental impact. In larger buildings (*i.e.*, hundreds of occupants; 100,000s gallons per year), graywater recycling systems produced recycled water at a cost equivalent to drinking water from a centralized treatment system and resulted in a net reduction in overall cumulative energy use (*i.e.*, global warming potential, GWP) (Arden et al. 2021). These benefits were due to several factors, such as avoiding costs associated with delivering drinking water to the building for non-potable uses. On the other hand, in the smallest buildings considered in those studies (50 occupants; 10,000 gallons per year), the recycled water cost was up to $0.08 per gallon and resulted in net increases in overall cumulative energy use (and also global warming potential) compared to centralized drinking water treatment.

The non-linear increases in costs and net energy use seen with decreasing building size strongly indicate that full-scale household graywater reuse systems would be even more costly and energy intensive than small building graywater reuse systems, and therefore also more so than centralized drinking water treatment systems. This analysis suggests economic costs and broader life cycle environmental impacts should not be part of the rationale for promoting household scale graywater treatment systems that use current technology recommendations of membrane bioreactor and/or advanced oxidation as assessed the Arden et al. (2021) study.

Alternative approaches to household scale graywater recycling, such as recirculating showers, may have more favorable energy use profiles due to the significant reduction in hot water heating requirements. Explicit life cycle analysis of recirculating showers has not been performed and would need to include the impacts of recommendations on operation and design to reduce risks from environmental pathogens (*e.g.*, the use of energy for UV treatment or pasteurization).

Summary of Life Cycle Assessment for Single-Family Water Reuse Applications:

- Due to economies of scale, single-family graywater systems are likely not energy efficient or cost effective when using current technology recommendations (*i.e.*, MBRs).
- While common treatment systems considered for single-family graywater systems (*e.g.*, MBR with UV and/or chlorine disinfection) may be sufficient to meet a virus LRT of 5.0, additional research is needed to identify more energy efficient treatment trains. The IAP is recommending that more energy efficient single-family graywater systems become available in the marketplace.
- Recirculating showers may have potential for lowering overall energy requirements due to their reductions in hot water heating.

9 IAP TECHNICAL AND POLICY RECOMMENDATIONS

Technical Recommendations:

- Amend IAPMO 330-2023 standard with the suggested IAP recommendations prior to advancing implementation of recirculating showers on a wide scale. Several members of the IAP are involved in the IAPMO Technical Subcommittee for the standard amendments which is currently underway.
- Amend NSF/ANSI 350-2023 standard to include the recommended LRTs for single-family residential settings and other recommendations from the IAP. Members of the IAP are engaged with NSF on this topic.
- Amend IAPMO/ANSI Z1324-2022 standard to include the recommended LRTs applicable to the single-family scale and other recommendations from the IAP.

Policy Recommendations:

- Encourage recirculating showers when IAPMO 330-2023 is amended in accordance with IAP recommendations.
- Encourage use of single-family graywater systems when NSF/ANSI 350-2023, IAPMO/ANSI Z1324-2022, and other relevant industry standards are amended to include the IAP recommendations, including applicable LRTs.
- If the marketplace for recirculating clothes washers further develops, the IAP recommends that a certification standard be developed for this application in accordance with the IAP recommendations.
- Recommend minimum virus LRTs of 5.0 and 3.0 for single-family graywater and recirculating clothes washers (with storage of graywater), respectively.
- Recommend continuous monitoring systems or local sensors to monitor system performance.
- Encourage single-family graywater systems that are energy efficient.
- Rebates can be given for single-family dwelling reuse appliances with the following conditions:
  - Treatment and BMP recommendations are followed;
  - Training is provided on potential risks, proper use, and maintenance;
  - A subscription to a maintenance package is obtained (rebates could cover annual maintenance packages);

- Upon sale of the dwelling, the new dwelling owner should be made aware of the graywater reuse system and be made aware of the conditions of the rebate if the system will continue to be used;
- An annual report or evaluation be provided by the user that includes items such as customer experience, ease of use, reliability, frequency of maintenance, frequency that the reuse mode was utilized, and estimated water savings.

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